NAVAL POSTGRADUATE SCHOOL
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THESIS

APPLICATION OF LIFE SUPPORT COST, PROVISIONING, AND REPAIR/DISCARD MODELS TO WEAPON SYSTEM PROCUREMENT DECISIONS BY SMALL COUNTRIES

by

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and

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December 1981

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I. INTRODUCTION

1.1. BACKGROUND

Small countries are not normally capable of satisfying all their military needs through internal manufacturing due to a lack of domestic resources. The required combination of large amounts of capital, raw materials, advanced technology, and skilled manpower needed for the establishment and operation of defense-oriented industries can rarely be found in small countries.

As a consequence, in fulfilling their military needs, such countries depend heavily on procurement from foreign defense industries which exist in large, well-developed countries. When a small country decides to procure foreign military equipment, the normal choice is between systems which are in an advanced stage of development or production, or have already been produced. Among the advantages of doing this, the following may be listed:

a) Savings in investment needed for research, development, and production.

b) Lower procurement cost per system (R&D expense is shared with other customers).

c) A co-production agreement may be possible which usually improves the state of the art of domestic industries by enabling the implementation of advanced technologies.

d) Experience and field data obtainable from other users of the same equipment eases system absorption and implementation.

Some of the disadvantages related to this situation are:

a) Lack of military independence (including a possibility of an embargo).

b) Limited possibilities of choice in procurement of new, highly-advanced systems/technologies.

c) A likelihood that common equipment is possessed by countries in a state of conflict.

d) Limited control of sales of co-produced systems to a third party.

In addition, a small customer normally buys small quantities of equipment. Thus, the possibility of significantly affecting the design of the equipment or its characteristics seldom exists. The only possible courses of action remaining are to procure the system and use it as it is or to modify it slightly so that it will better fit the specific requirements and the environment in which it will be used.

This description fits the existing conditions in such countries as Denmark and Israel, both of which fulfill their military needs mainly by means of procurement from foreign Western sources (except for a relatively modest portion of military demands supplied by domestic production). In this case, the major issue is to decide among competitive systems being offered for foreign military sales by allied Western countries.

The situation described above may imply the use of advanced procurement methods and techniques, enabling the

best "scientifically" based decision to be reached with the most cost-effective system being chosen. Unfortunately, this is not the case. The procurement decision procedure which is applied may often be viewed as overly simplified, based mainly upon some cost considerations. The effectiveness part of systems evaluation is stated in general terms of performance and operational capability without detailed quantitative definitions of availability or operational readiness terms of the system under consideration. Hence, reliability and maintainability factors remain in the background, affecting only indirectly the procurement decision.

The cost part of the evaluation is mainly based upon two factors:

a) procurement cost

b) cash flow

These two elements may be viewed as "present cost oriented factors" where the main emphasis is on expenditure in the near future, partially because of tight present budgetary constraints. Other costs which appear during the Use Period of the system are ignored. Thus, after a preliminary screening process has reduced the list of systems being considered for procurement, these two cost criteria are applied. The result of this may be that the "cheaper" system (the one having lower procurement cost and/or more convenient cash flow schedule) is selected, although the total life cycle costs may be substantially higher than those of one of the systems it competes against. Since the Use Period costs may be several times the initial

acquisition cost of the system, the decision reached might be inappropriate.

1.2. OBJECTIVE

The objective of this thesis is to suggest an approach related to the procurement decision process which will enable better system acquisition decisions to be made. This is accomplished by:

a) introducing effectiveness concepts;

b) highlighting the major factors affecting the Use Period support costs, and evaluating their relative importance;

c) presenting possible trade-offs between support cost elements and system design characteristics; and

d) implementing advanced techniques which enable attainment of optimal results concerning life support cost.

Additional goals are:

a) to present models for the determination of initial procurement of spares; and

b) to establish a method for facilitating repair/discard decisions concerning spares.

This study concentrates upon specific parts of the procurement decision process, uses a defined approach applied for a specific type of system, applies existing tools and techniques, and suggests new methods and procedures.

1.3. MEASURE OF COST

The methodology frequently applied for procurement decisions is the well-known Life Cycle Cost (LCC) approach [Ref. 1]. But implementing LCC, especially with regard to the situation existing in small countries, may be impractical for the following reasons:

a) The very large amounts of data required (especially many cost elements) are extremely difficult to obtain. The time and the effort needed for use of the LCC approach, when compared with the reliability of the results obtained, make its use questionable.

b) Many procurement decisions in military organizations are made subject to severe time constraints, resulting in a preference for using "quick and dirty" methods in decision processes. The LCC approach can hardly be considered as one of these.

c) Normally, some portions of the R&D and Production Costs will be allocated by the manufacturer to the selling price of the system and therefore, considered to be a part of the Acquisition Cost. As a consequence, a simplified approach may be used in the procurement decision process, which takes into consideration the Acquisition Cost and the Operations and Support Costs. In this thesis, only the Life Support Costs are explored.

1.4. TYPES OF EQUIPMENT

Different categories of systems and equipments cannot be treated in the same manner with respect to their availability

characteristics because of peculiar considerations which have to be applied for each type. As a consequence, this thesis considers only one type of system. The most appropriate one seemed to be the electronic type, which is widely used by military organizations. Furthermore, electronic systems have been extensively studied and extensive reliability and maintainability data collected. For example, experience with electronic systems has shown that they often exhibit the phenomenon of a constant failure rate. In this case, failure occurrence fits the well-known Poisson distribution, and the times between failures are exponentially distributed [Ref. 2], enabling relatively easy handling of computations. Another feature of electronic systems is that maintainability is usually concerned with corrective maintenance; while preventive maintenance is limited to such activities as tests, calibrations, and performance monitoring. Corrective maintenance times fit, to a large extent, the log-normal distribution [Ref. 3]. A convenient mathematical evaluation of the system effectiveness can be made as a consequence of the Poisson failures and log-normal repair times.

1.5. APPROACH

Having verified the needs for a new system, defined the operational requirements, specified the assumptions, and defined the objective, the remaining problem is how to choose among the alternative courses of action. A cost-effectiveness analysis [Ref. 4] is commonly used for this

purpose. It involves measures of effectiveness (benefits) and costs, and enables the decisionmaker to improve the quality of his decisions. Comparison of alternatives is accomplished by use of graphical or computational techniques, leading to a ranking of the alternatives according to one of the following criteria:

-- minimum cost for a given effectiveness;

-- maximum effectiveness for a given cost, and

-- maximum cost-effectiveness, using cost and effectiveness as variables.

1.5.1. Main Assumptions

In this thesis, it is assumed that:

a) the systems considered for procurement are already produced or in production (acquisition cost is known);

b) an estimate of costs of operations is available;

c) system availability is an adequate measure of effectiveness.

Where more specific assumptions are used, they are stated in the appropriate sections.

1.5.2. Cost-Effectiveness Evaluation

The main assumptions reduce the expenditures to be explored to Life Support Costs (LSC). For a required system availability, LSC is determined by system characteristics (such as mean-time-between-failures and mean-time-to-repair a failed system), the organizational structure (e.g. the number of maintenance levels), and other factors (e.g. the support policy). Although all cost-effective elements illustrated in Figure 1-1 are interrelated, within the assumptions stated above, the investigation in this thesis is limited to relations with arrows.

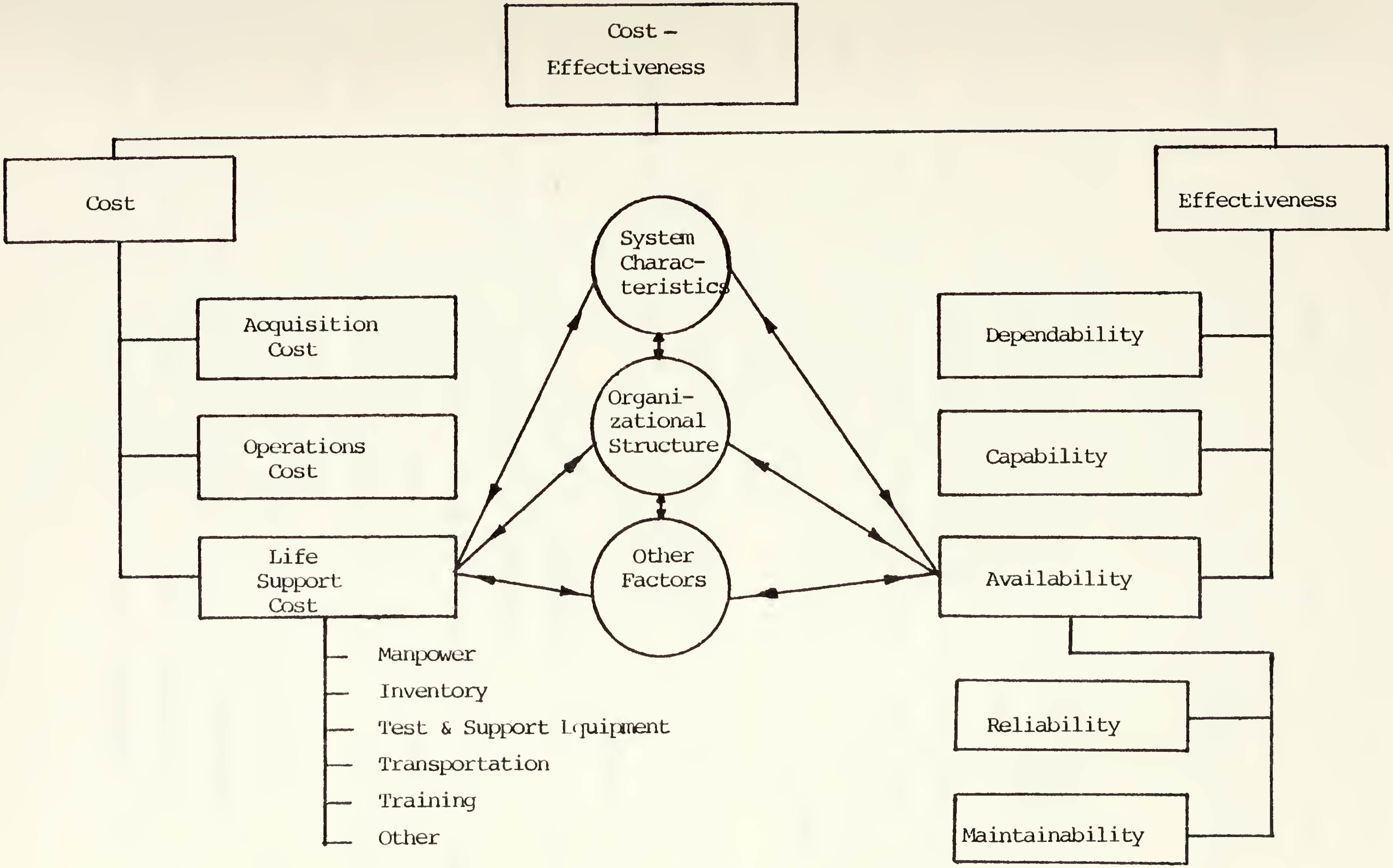


Figure 1-1. Cost-Effectiveness Analysis

A partial cost-effectiveness analysis based on LSC and system availability may not lead to the optimal choice. To obtain this, other relevant elements of cost and benefits and non-economically quantifiable aspects may have to be included in the analysis.

1.6. THESIS STRUCTURE

The structure of this thesis and the relations between chapters and appendices are illustrated by Figure 1-2.

Chapter II introduces the reader to the system life cycle, the concept of system effectiveness, life cycle cost, and cost-effectiveness analysis. More detailed descriptions of the system life cycle and cost-effectiveness are given as Appendices A and B, respectively.

Chapter III describes the tasks and the time elements associated with repair of a failed item. LSC is broken down into categories, each including several cost elements for which equations are developed. A procedure for determination of the lowest LSC alternative is described.

Chapter IV discusses repair/discard decisions. Simplified delta cost equations--computing the cost difference between the repair and discard alternative--are developed and used to obtain a screening rule.

Chapter V includes a description of the models used for a numerical example. OPUS-VII is a model (developed by the Swedish company Systecon AB) for initial procurement, effectiveness evaluation, reallocation of a given assortment, and

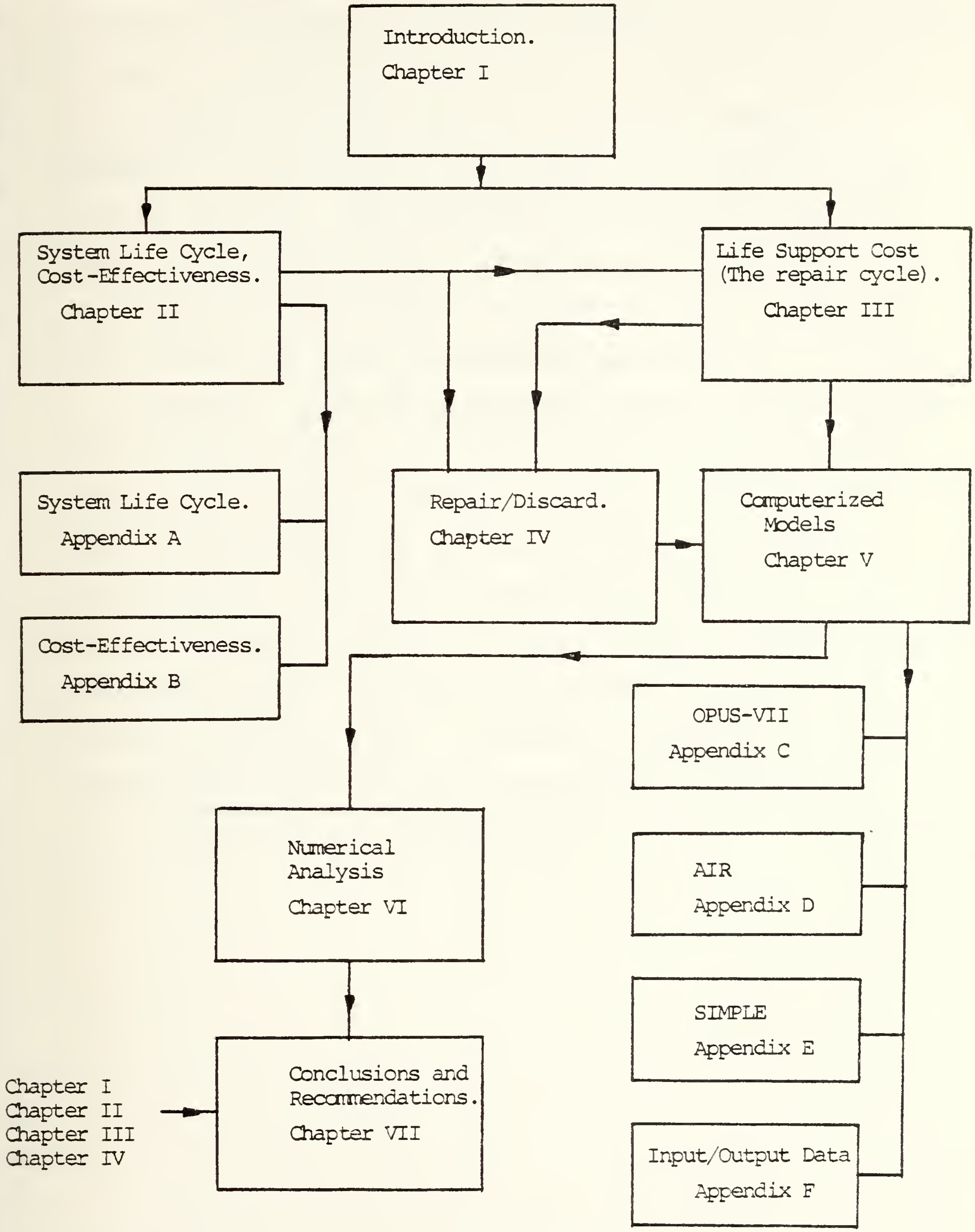


Figure 1-2. Thesis Structure

replenishment procurement of spares. A more detailed description of this model is found in Appendix C. AIR is a level-of-repair and LSC model used by the U.S. Navy. A comprehensive discussion of this model is included as Appendix D. SIMPLE is a simplified tool for computation of LSC and repair/discard decisions. This model was developed by the authors based on an approach used in the Swedish Air Force, and on the equations developed in Chapters III and IV. The computer program for SIMPLE is found in Appendix E.

Chapter VI includes a numerical example illustrating the use of these models for a specific system in a given support organization. Special emphasis is paid to initial procurement of spares, which may account for an essential part of LSC and which is the most difficult issue to handle in the decision process. Further analysis includes the impact of the organizational structure, system characteristics, and selected variables on LSC. Examples of computer output obtainable from the models used are enclosed as Appendix F.

Conclusions and recommendations are found in Chapter VII.

II. SYSTEM LIFE CYCLE AND COST-EFFECTIVENESS RELATIONSHIPS

2.1. SYSTEM LIFE CYCLE

A basic knowledge of the System Life Cycle concept is fundamental for the understanding of the cost-effectiveness approach to be presented in this thesis. It is during the early phases of the System Life Cycle that a system's effectiveness characteristics are determined, and this establishes the quantitative basis for trade-offs between subsequent effectiveness and cost elements.

The System Life Cycle represents the phases through which any system passes, and the different activities which take place during these phases. A detailed description of the System Life Cycle is presented in Appendix A.

Any system is designed and produced as a result of one or more of the following:

a) New threats or needs.

b) Changes in the state of the art (new technology).

c) Existing system obsolescence.

Each of these causes can be found in a military environment, but the first one has the strongest impact of all three, particularly in countries involved in confrontations or conflicts. Here, threats change continuously and push the parties involved towards a continued development or procurement of modern weapons systems (Middle East, for example).

The System Life Cycle is illustrated by Figure 2-1. It starts with the <u>Planning Period</u>, during which the

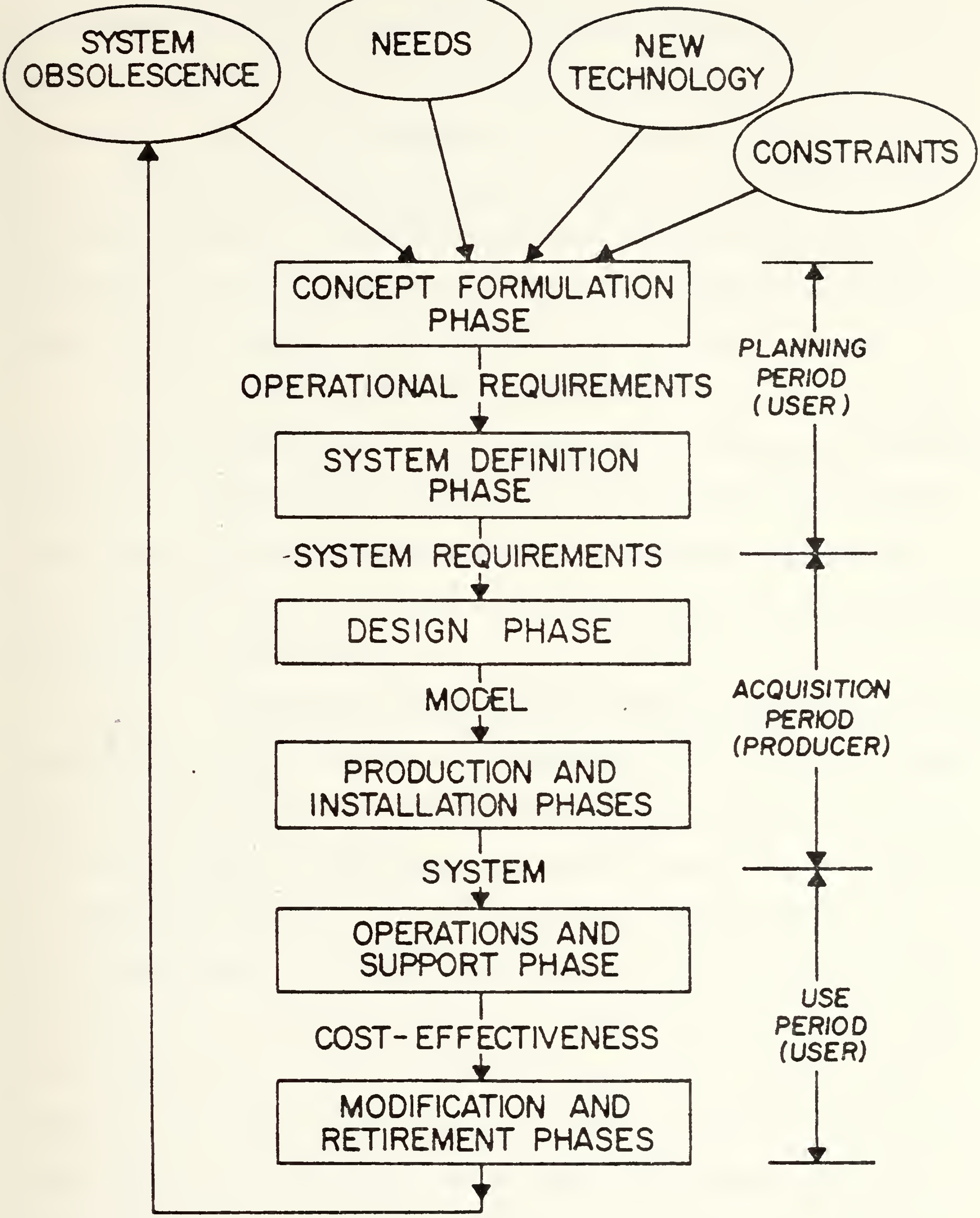


Figure 2-1. System Life Cycle [Ref. 5]

need for a new system is verified, and system concepts are formulated. The operational environment and resources available are considered (thus limiting the variety of possible solutions), and system feasibility is determined by consideration of operational, technological, economic, political, legal, and other aspects. At the end of this period the system is defined by a set of design requirements to meet the operational needs and its further development is justified.

Small countries usually have little or no impact on the Planning Period. As a consequence, they have to decide whether to commit themselves to the system being formulated, or to start research and development efforts for a system more adequate for their needs. In most cases the self-development alternative is abandoned.

The Acquisition Period includes the design, test, evaluation, production, and installation of the system. Some small countries may be involved during this period, especially if they are able to perform tests of the system in an operational or combat environment. It is during the design phase that the effectiveness characteristics, specified as a set of requirements in the previous period, are converted into a hardware system which can be tested and verified. Often, some redesign and modification of the system is made as result of these tests. At the end of this phase, the specifications for the system, previously agreed upon between the customer and the producer are demonstrated, or modified as a result of cost-effectiveness evaluation. The effectiveness values achieved

and cost estimates for the operational period of the system, such as Operational Availability and Life Support Cost, are accepted by both parties. At this point in time, the responsibility for the eventual operation and support of the system is transferred to the customer.

The selected system may not provide an optimal solution for every potential customer after the first one. These later customers may be forced to make compromises with their requirements because they need to purchase the system.

The Use Period includes all the operation and support activities. It is obviously the longest and the most expensive period of the life cycle. Sometimes changes are introduced into the system during this period as a result of problems detected from actual use in an operational environment. The Use Period ends with the retirement of the system from active service, when it is no longer cost-effective to operate and support the system.

2.2. COST-EFFECTIVENESS

Cost-effectiveness analysis provides a conceptual framework and methodology for the systematic investigation of alternatives.

It enables the user to choose the preferred alternative out of many approaches. The concept relates the measure of each alternative in terms of cost (the total expenditure for each alternative during the life cycle) to its effectiveness

(the level of mission fulfillment by that alternative). By applying the analysis procedure, it becomes possible to select the optimal alternative for achievement of the goals defined within the allowed constraint boundaries.

Of these two elements, cost is easier to measure and handle because it can be expressed by a single, monetary value. Effectiveness is harder to deal with. It can be presented both in terms of certain parameters which have clear-cut numerical representations and others which are not readily quantifiable. This thesis concentrates on quantifiable effectiveness measures that can be defined by mathematical formulas and expressions, such as Operational Availability.

It is recognized that political, social, and other non-quantifiable aspects are of great importance in any decision process. However, their treatment is considered to be of such complexity as to be beyond the scope of this thesis.

The following discussion describes cost and effectiveness terms with regard to a procurement decision process. A more detailed description is presented in Appendix B.

2.2.1. System Effectiveness

System effectiveness is a measure of the ability of a system to fulfill its mission in a specific environment. It is used as a prediction tool during the planning and design phases of the life cycle, and should be evaluated continuously as system development proceeds, to enable the obtaining of an objective measure of fulfillment of system needs.

System effectiveness is expressed in quantitative terms based upon a probabilistic approach. It is primarily concerned with system performance, availability, and dependability, all of which have strong relationships with logistic policies implemented.

In recent years, a variety of models and definitions of system effectiveness have been developed using different concepts of effectiveness. One example is illustrated in Figure 2-2. These models base their measures upon combinations of terms such as mission reliability, operational readiness, availability, design adequacy, capability and utilization. Of all these terms, availability is the one most commonly used, and will be emphasized in this thesis. Although several types of availability are defined (Inherent, Achieved, and Operational), the one considered to be important for effectiveness evaluation purposes during the Use Period of the system is Operational Availability (A_o). It is more closely related to the actual operational environment than the other two measures and is affected more by user decisions than the others. It is defined as [Ref. 6]: major element of system effectiveness

$$A_o = \frac{MTBM}{MTBM + MDT},$$

where

MTBM = mean-time-between maintenance.

MDT = mean down time.

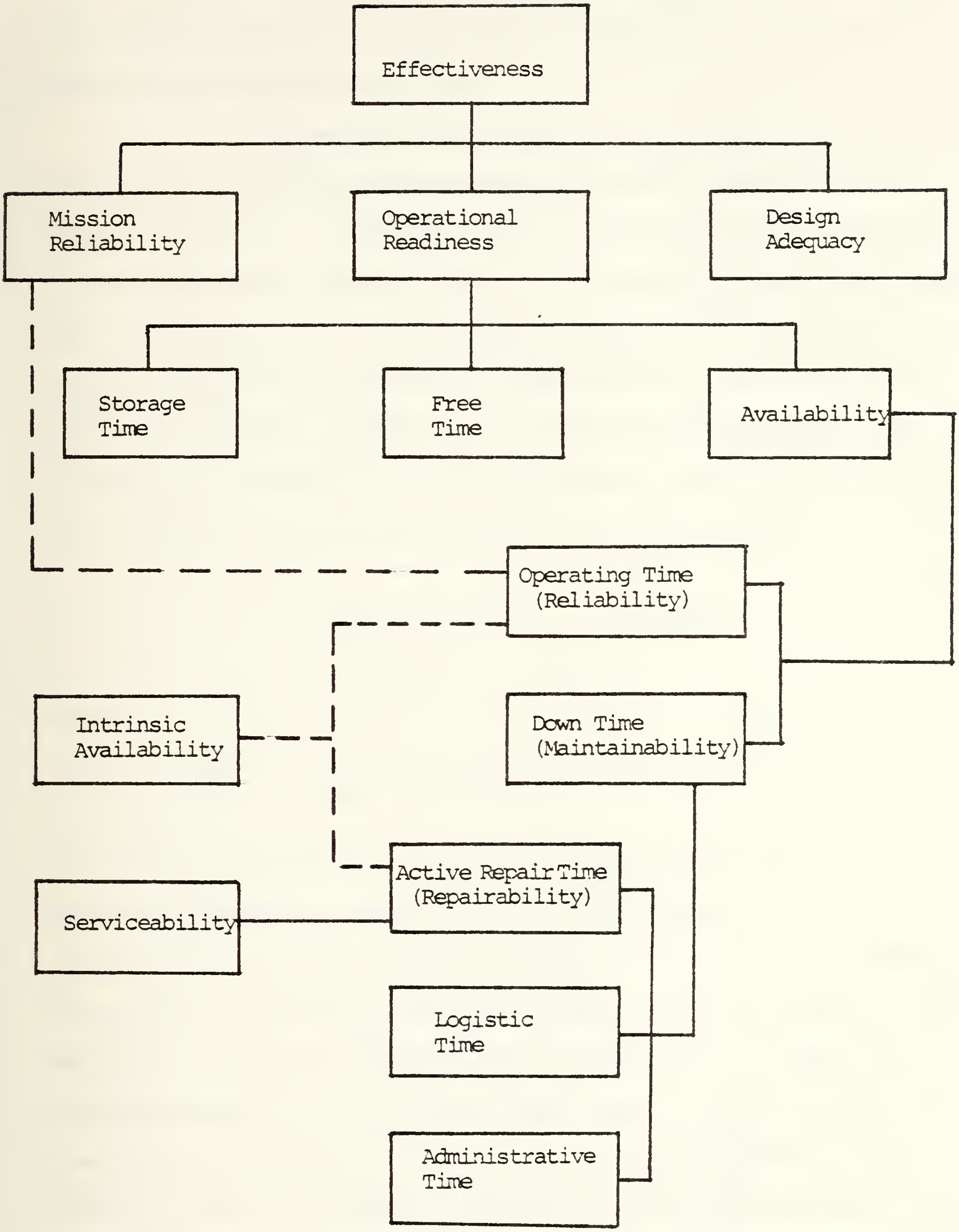


Figure 2-2. Concepts Associated with System Effectiveness [Ref. 7]

Availability concerns itself with the Operating Time (Reliability) and Down Time (Maintainability), both being system design characteristics.

In dealing with electronic systems, the failure rate (λ) can often be considered as constant through the Use Period [Ref. 2]. It enables one to fit a Poisson distribution to the number of failures which occur during a given time interval in a system. As a consequence, the times to failure can be described by an exponential distribution. Reliability is defined to be the probability that the system survives over a given time interval. It is therefore a function of time (t) and can be described mathematically by the formula:

$$R(t) = e^{-\lambda t} = e^{-t/MTBF}$$

where

MTBF = Mean Time Between Failures.

The design for maintainability directly affects many of the resources needed for performance of the support activities during the life cycle: test and support equipment, maintenance facilities, personnel, spares and repair parts, training equipment, and technical documentation. These play a major role in determination of life cycle cost, accounting for more than the procurement cost. In particular, MDT includes all time elements needed to retain the system or restore it to an operational condition (preventive and corrective maintenance) as

well as administrative and logistic times. The user should minimize those aspects of these time elements within his control if he expects to maximize the operational availability.

Experience has shown that reliability and maintainability predictions provided by the manufacturer tend to be over-optimistic. The value of the MTBF, even if proven in a demonstration test, usually turns out to be several times lower when the system is placed in the actual operational environment [Ref. 8]. In addition, actual repair times obtained in the field, exceed up to several times those of a maintainability demonstration [Ref. 9]. These facts should be seriously considered when using reliability and maintainability data for effectiveness and cost predictions, and when applying cost-effectiveness analysis.

2.2.2. Life Cycle Cost

The Life Cycle Cost (LCC) of a system consists of all costs which are incurred during the complete system life cycle.

The development of the LCC for use in system evaluation was motivated by the fact that the major part of user budgets are spent on operations and support activities. Furthermore, it was recognized that these ownership costs exceed systems procurement costs by up to several times. The main motivation behind the LCC method is to make trade-offs possible which enable savings to be made during the Use Period by increasing expenditures during the Acquisition Period, and thus to lower the total cost of the system.

LCC is usually broken down into three main cost categories (Figure 2-3).

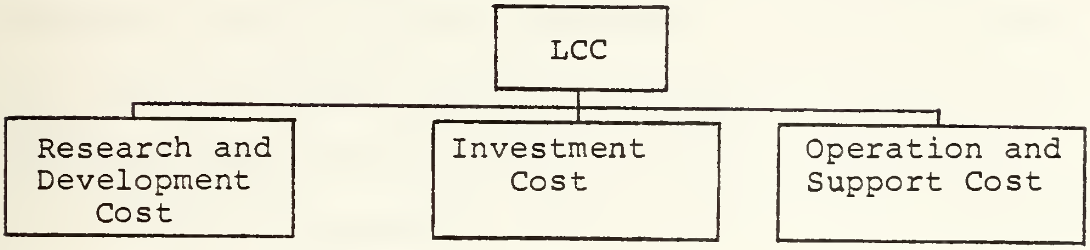


Figure 2-3. A Typical LCC Breakdown.

The first, Research and Development, includes all costs accumulated during the conceptual, definition, and full-scale development phases (systems engineering studies, design drawings and specifications, development, prototype fabrication and testing, operation and support planning, etc.).

The second, Investment, includes recurring and non-recurring costs of the production phase (tooling, test and support equipment, new facilities, training, manufacturing, labor, material, and inspection). The direct costs are charged to the particular piece of equipment being produced, while the indirect costs are proportionally allocated to it as overhead.

The third cost category includes Operations and Support Costs. Operations Costs are recurring costs spent on operating personnel, energy and operating support. They include expenditures on training, recruitment, retirement, salaries, housing, food, clothing, tools, and medicines for

the operating personnel; utilities, petroleum and oil, and different facilities for operating the equipment. Support Costs include all costs of maintenance, spare parts, provisioning, test and support equipment, training of support personnel, transportation, documentation, and facilities. The main cost elements found in Support Costs are:

a) Maintenance Costs--associated with the performance of corrective and preventive maintenance activities. These are a result of system design and the maintenance concept established for the system.

b) Inventory Costs--includes expenditures for initial and replenishment procurement of spares and repair parts, and for supply management (entering and retaining of items in inventory).

c) Test and Support Equipment Costs--includes procurement and maintenance costs for test equipment, tools, and material handling equipment.

d) Training Costs--all costs associated with the training of support personnel.

e) Technical Documentation Costs--for technical manuals and drawings.

f) Transportation, Handling and Packaging Costs--includes costs of packaging, preservation, handling and moving of spares and repair parts and material in the maintenance and support organization.

Many of the LCC models have an element called Miscellaneous Costs. These may include new or modified construction of facilities needed for operating the new

systems, site preparation, security requirements, and disposal or salvage value.

From the discussion above, it is easy to see that taking into account all relevant cost elements may be a difficult task because it requires a large effort, many resources, and longer computation times. In addition, the accuracy and the reliability of the input data (and, therefore, of the output data, as well), is often questionable. Fortunately, many of the cost elements are of a low magnitude, and do not affect significantly the results obtained. Concentration upon those cost elements that have significant influence on the results (the so-called "cost drivers") is usually sufficient.

2.3. COST-EFFECTIVENESS TRADE-OFFS

Any system is a result of trade-offs and compromises performed during different phases of its development and use. These trade-offs may be divided into two major categories.

The first category, system effectiveness trade-offs, includes those pertaining to various characteristics of the system, such as reliability, maintainability, and availability. It is possible to produce a highly reliable (low failure rate) or a highly maintainable system (quickly restored), but the same operational availability may also be achieved by trade-offs between these two. The most suitable balance between them may be based on the relative costs.

Another category includes trade-offs among cost categories. Higher investments during the R&D phase may reduce

production costs, and both may increase or decrease expenditures during the Use Period of the system (O&S costs).

These two major categories usually do not occur independently of one another. Decisions with regard to module size, repair policies (maintenance level and repair vs. discard), types of maintenance (corrective vs. preventive), level of automation, human factors (man vs. machine), and packaging influence costs as well as system performance. As a consequence, the composite or cost-effectiveness balance should be sought which allows the user to have the best system possible subject to technological and budgetary constraints.

In cases where equipment is bought "off the shelf," the spectrum of trade-offs is limited because many design features are already built into the system.

III. LIFE SUPPORT COSTS

3.1. INTRODUCTION

Life Support Cost (LSC) includes the cost of personnel, equipment, facilities, materials, and other direct or indirect costs necessary to support and maintain a system during the operational and support phase of its life cycle.

LSC is dependent on the operational requirements, system characteristics, and the support organization, including the repair and the stockage policy. To understand the interactions between the elements affecting LSC, a knowledge of the repair cycle is necessary.

3.2. THE REPAIR CYCLE

As indicated in Section 2.2., operational availability is defined as

$$A_o = \frac{MTBM}{MTBM + MDT}$$

For many electronic systems the failure rate is relatively constant throughout most of the system use period. Therefore, preventive maintenance is primarily concerned with periodic test and checkout, adjustment, and calibration. Most of these actions can be performed while the system is operating and hence do not prevent the system from being ready for operations almost immediately if necessary. Certain preventive maintenance actions which might involve longer times can normally be

scheduled so that they do not interfere with operations. As a consequence, preventive maintenance for electronic systems can be viewed as having only a minor impact upon operational availability and therefore A_o can be approximated by

$$A_o \approx \frac{MTBF}{MTBF + MDT}$$

where MDT includes active corrective maintenance time, logistics supply time, and administrative delay time.

LSC is heavily affected by the required system availability, and therefore, by MDT. A formula for MDT is developed below under the following assumptions:

a) The system is built up of a number of Line Replaceable Units (LRU), each containing a number of Shop Replaceable Units (SRU) which, in turn, contain a number of non-repairable parts. The MTBF for LRU's, SRU's, and the most important parts are known.

b) The support organization has organizational level, intermediate level, and depot level maintenance capabilities. At the organizational level failed LRU's will only be replaced and sent to a higher echelon for repair. Therefore, only LRU's are allowed to be stocked at organizational level. At the intermediate level, LRU's, SRU's, and repair parts are stocked if it is cost-effective to do so. SRU's and repair parts can be stocked at the depot level.

c) The various elements which make up the turnaround times (TAT) for items in the repair cycle are statistically independent,

as is the failure of any one item with respect to other items.

d) Mean values of transportation times, administrative and other delay times, and maintenance times are known.

e) Demands are Poisson distributed.

f) SRU's cannot be repaired at a lower level of the support organization than that at which the repair of the LRU to which they belong takes place.

g) All LRU's and all SRU's are repaired (repair/discard decisions are discussed in Chapter IV).

3.2.1. Formula for $\overline{MDT}$, the System Mean Downtime

$\overline{MDT}$ includes the total time elapsed from when a failure is detected until the system is restored to an acceptable condition. This period is divided into

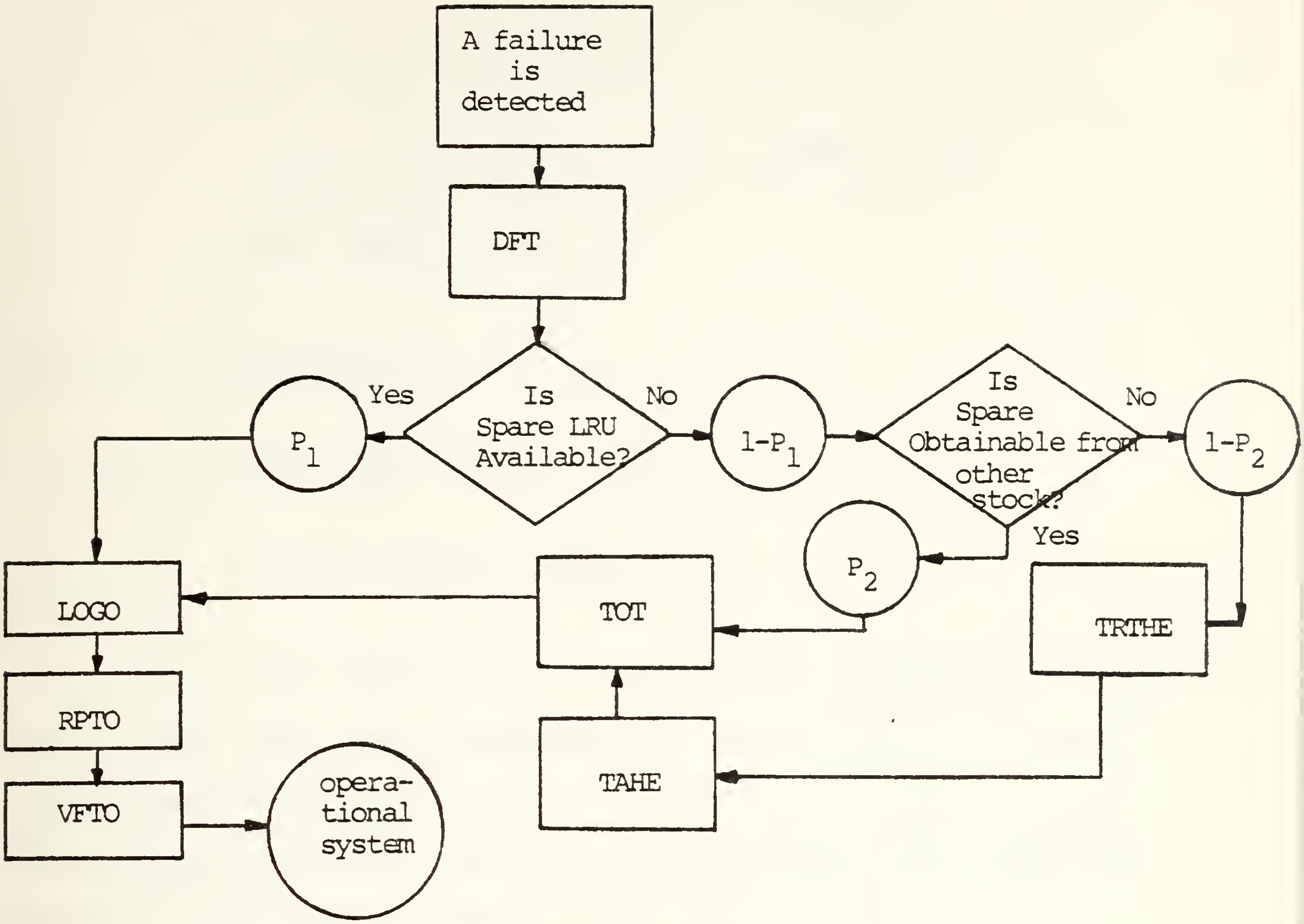
a) diagnosis time, the time it takes to locate the failure to a specific LRU,

b) correction time, which includes the time it takes to get tools, time to remove the failed sub-unit, time to get the spare from own stock, replacement time, and a closing time,

c) verification time, which is the alignment, calibration, and check-out time.

The system repair cycle is illustrated in Figure 3-1; for each module average values are used for all elements of time.

The following formula is derived from Figure 3-1:



DFT	=	Diagnosis and fault isolation time.
P_1	=	The probability that a spare LRU is in own stock.
P_2	=	The probability that a spare LRU is obtainable from a stock.
LOGO	=	Logistic time at organizational level.
RPTO	=	Time to replace a failed LRU.
VFTO	=	System verification time.
TOT	=	Time to get the LRU from another stock, given itis available
TRTHE	=	Transportation time to the echelon which repairs the failed LRU.
TAHE	=	Time until a repaired LRU will be available at the stock (formula developed below).

Figure 3-1. The Repair Cycle, Organizational Level

$$MDT = DFT + P_1 \times (LOGO + RPTO + VFTO) + (1-P_1) \times [P_2 \times TOT + (1-P_2) \times (TRTHE + TAHE + TOT) + LOGO + RPTO + VFTO],$$

which can be reduced to

$$MDT = DFT + LOGO + RPTO + VFTO) + (1-P_1) \times [TOT + (1-P_2) \times (TRTHE + TAHE)]$$

The notation is for a specific LRU. The values of P_1 and P_2 will vary as functions of which LRU failed and of the initial procurement of LRU's (Appendix C). Since also the time elements may vary from one LRU to another, the mean downtime for the system becomes

$$\overline{MDT} = \sum_{i=1}^{m} MDT_i \times P_i$$

LOGO, TOT, and TRTHE can be considered as independent of which module has failed. Furthermore, it is assumed that the variation in RPTO and VFTO from one module to another is insignificant. If so, the formula for $\overline{MDT}$ can be reduced to:

$$\overline{MDT} = \sum_{i=1}^{m} P_i \times \{DFT_i + LOGO + RPTO + VFTO + (1-P_{1i}) \times [TOT + (1-P_{2i}) \times (TRTHE + TAHE_i)]\},$$

where m is the total number of LRU's in the system, and P_i is the probability of the failure being located to LRU number i. The probabilities P_{1i} and P_{2i} are functions of the initial procurement, the MTBF of the LRU, the turn-around time of a failed LRU, and the stockage policy. Formulas for the probabilities are given in Section 3.2.2.

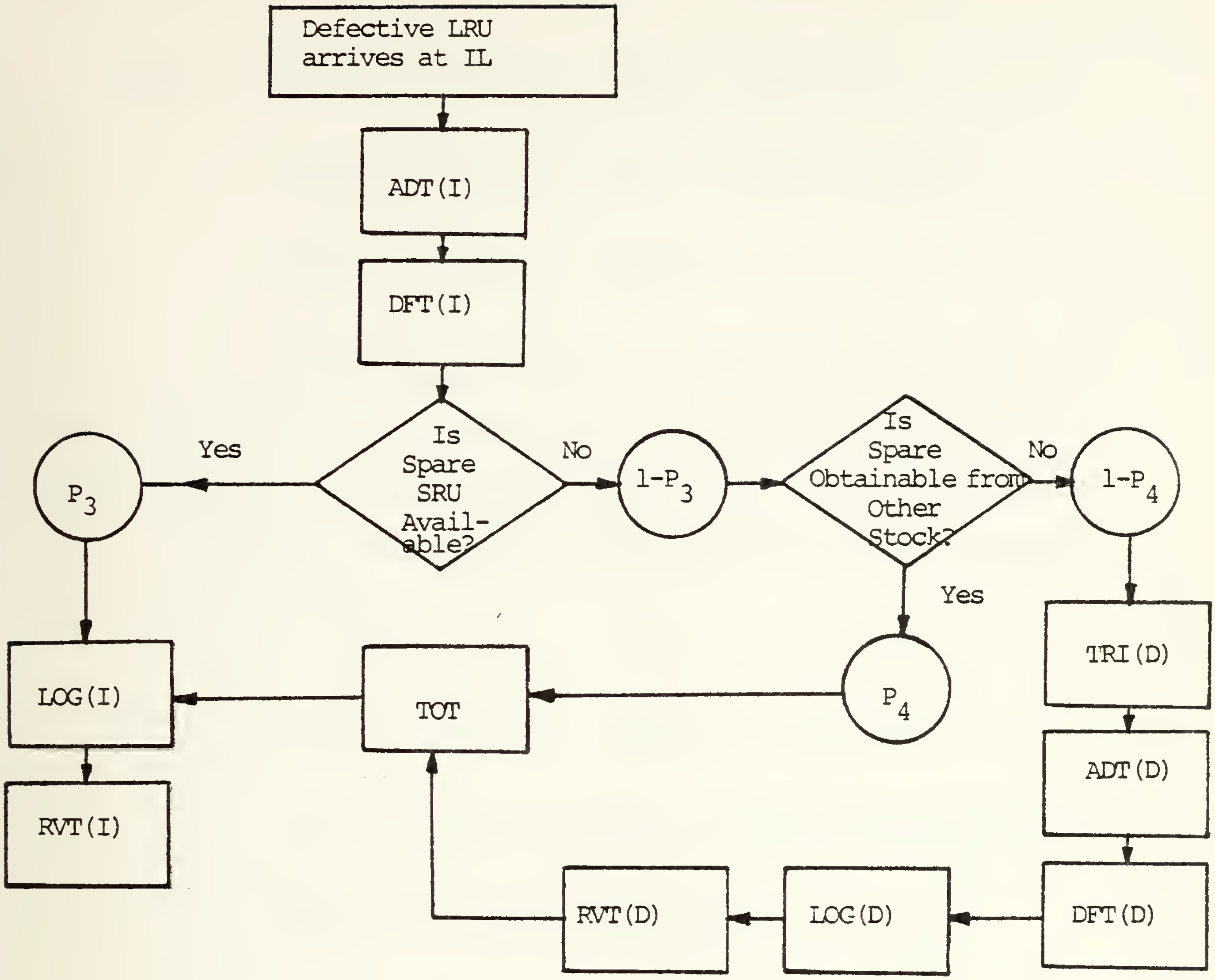
TAHE is the average time between the time a requisition is submitted and the time that a repaired LRU is available given that it was not so when demand occurred. The TAHE is a function of the level of repair policy, the mean turn-around time at the higher echelon (TATHE), and the quantity in the initial procurement of LRU's.

To compute TAHE, the first step is to develop a formula for TATHE. The most complex case is when the LRU is repaired at intermediate level and its SRU's are repaired at depot level. The formula developed for this maintenance policy can easily be modified to fit any policy by setting some of the time elements to zero.

Based upon Figure 3-2 and assuming that the LRU failed due to an SRU, the formula for TATHE for this maintenance policy is

$$\begin{aligned} \text{TATHE} = {} & \text{ADT(I)} + \text{DFT(I)} + P_3 \times [\text{LOG(I)} + \text{RVT(I)}] + \\ & (1-P_3) \times [P_4 \times \text{TOT} + (1-P_4) \times (\text{TRI(D)} + \text{ADT(D)} + \\ & \text{DFT(D)} + \text{LOG(D)} + \text{RVT(D)} + \text{TOT}) + \text{LOG(I)} + \text{RVT(I)}] \end{aligned}$$

or



(I)	=	is for intermediate level; (D), depot level.
ADT	=	Administrative delay time.
DFT	=	Diagnosis and fault isolation time.
LOG	=	Logistic time.
RVT	=	Replacement and verification time.
P_3	=	The probability of a spare SRU being at own stock.
P_4	=	The probability of a spare SRU being obtainable from another stock.
TOT	=	Time to get an SRU from outside stock, given it is available.
TRI(D)	=	Transportation time from intermediate to depot level.

Figure 3-2. TATHE, LRU Repaired at Intermediate Level and its SRU is Repaired at Depot Level

$$\text{TATHE} = ADT(I) + DFT(I) + LOG(I) + RVT(I) + (1-P_3) \times [TOT + (1-P_4) \times (TRI(D) + ADT(D) + DFT(D) + LOG(D) + RVT(D))]$$

The notation is for a given LRU and a given SRU. The values of P_3 and P_4 will vary as functions of which SRU failed and of the initial procurement of SRU's (Appendix C). If there are "ℓ" SRU's in the specific LRU, the average turn-around time is

$$\text{TATHE} = ADT(I) + DFT_i(I) + LOG(I) + RVT(I) + \sum_{j=1}^{\ell} P_j \times (1-P_{3j}) \times [TOT + (1-P_{4j}) \times (TRI(D) + ADT(D) + DFT_j(D) + LOG(D) + RVT(D))],$$

where P_j is the probability that the failure was due to SRU number "j". P_j is computed as

$$P_j = \frac{MTBF(LRU_i)}{MTBF(SRU_j)} .$$

An LRU can fail due to various reasons, not only due to an SRU. If P_5 is the probability that the LRU failed due to an SRU, then $(1-P_5)$ is the probability that the failure is not located to an SRU, and the formula for TATHE will be:

$$TATHE = ADT(I) + DFT_i(I) + LOG(I) + RVT(I) + \sum_{j=1}^{\ell} P_j \times (1-P_{3j}) \times [TOT + (1-P_{4j}) \times (TRI(D) + ADT(D) + DFT_j(D) + LOG(D) + RVT(D))] \times P_{5j}$$

In the case where no SRU's are procured for stockage, the value of TATHE computed above will be the value of TAHE as well. Assuming that a given number (n) of SRU_j are purchased, that items in the repair cycle are equally spaced in time, and that the number of demands (X) during the last period of time equal to TATHE is greater than n, ($P_{4j} = 0$), a new demand will be number (X+1). The time spacing in the repair cycle will be TATHE/(X+1). Since n SRU_j's are meant for stock, the first (X-n) SRU_j's which finish the repair cycle belong to other systems, and the average waiting time, TAHE will be

$$TAHE = TATHE \times (X+1-n)/(X+1).$$

3.2.2. Factors Affecting $\overline{MDT}$

For a given value of MTBF and a required operational availability ($A_o \simeq MTBF/(MTBF + MDT)$), the maximum acceptable value of $\overline{MDT}$ is

$$\overline{MDT} = \frac{MTBF(1 - A_o)}{A_o}$$

Experience has shown that the system MTBF for military equipment in operational use, is as low as one sixth

of the value obtained during the reliability demonstration [Ref. 8]. The reasons for the difference include: (1) additional stress in the operational environment, (2) improper use of the system, (3) insufficient training of operators and maintenance personnel, (4) early wearout of some parts, and (5) insufficient planning or poor conduction of the reliability demonstration. The impact of a lower MTBF is best seen by rewriting the formula for A_o given in Section 3.2.,

$$A_o \approx \frac{MTBF}{MTBF + MTTR + MADT + MLDT}$$

$$= \frac{1}{1 + \frac{MTTR + MADT}{MTBF} + \frac{MLDT}{MTBF}}$$

where MTTR is the mean corrective maintenance time, MADT is the mean administrative delay time, and MLDT is the mean logistic delay time.

The MTTR and MADT can be assumed to be unaffected by MTBF. However, MLDT may be a function of MTBF. In the formula for $\overline{MDT}$ developed above (Section 3.2.1), the MTBF was not shown explicitly but was "hidden" in the probabilities of spares being available.

Given demands are Poisson distributed, the probability of exactly X demands for a specific item during a period of time of length TATHE is

$$P_X\{x = X\} = e^{-(TATHE/MTBF)} \times \frac{(TATHE/MTBF)^X}{X!}.$$

The probability (P) of a specific item being available from stock is a function of the quantity (n) of the item procured for the stock, the turn-around time (TATHE) for the item, and the MTBF,

$$P = \sum_{x=0}^{n-1} e^{-(TATHE/MTBF)} \times \frac{(TATHE/MTBF)^{x}}{x!}$$

The probability that a demand cannot be satisfied is

$$1-P = \sum_{x=n}^{\infty} e^{-(TATHE/MTBF)} \times \frac{(TATHE/MTBF)^{x}}{x!} .$$

These formulas illustrate that a lower MTBF will result in a lower value of P and a higher value of (1-P), which will give a higher value of MLDT. The total effect on the term (MLDT/MTBF) is an increasing numerator and a decreasing denominator, with the net effect of increasing the value of this ratio. As a consequence, the value of A_o will be reduced. Additionally, LSC will increase because more labor and more transportation are needed as well as other LSC elements possibly being affected by the higher number of repair actions.

To achieve the originally specified availability, one or more of the following alternatives may be considered:

a) modification or complete redesign of modules having high failure rates to improve system MTBF,

b) additional investment in spares to reduce the turn-around time, or

c) reduction of the time elements of the repair cycle to reduce the turn-around time.

The reduction of one of the time elements in the formula for mean down time ($\overline{MDT}$) (Section 3.2.1) creates a favorable chain reaction. If, for example, the administrative delay time at depot level is reduced, the direct effect is a reduction of the turn-around time, which has the following consequences: a higher probability of spares being available at this level (seen from the formula for Poisson probability), which gives an additional reduction of the turn-around time from intermediate level, increasing the probability of spares being available at this and the organizational level as well. The resultant total reduction of $\overline{MDT}$ may be several times greater than the decrease of the administrative delay time.

The diagnosis, fault isolation, logistic, replacement, and verification time at the organizational level are direct parts of $\overline{MDT}$ and should, therefore, be kept at low values if a high system availability is required. The same elements are also parts of the repair time at intermediate and depot level. Additionally, for both levels we have transportation time and administrative delay time. These time elements are primarily functions of system design, the number of people trained and assigned to the tasks, space available, test and support equipment, and organizational factors.

3.3. THE COMPONENTS OF LIFE SUPPORT COSTS

As was implied by the repair cycle, investment is required for spares, test and support equipment for repair of

the system and its sub-units, training of personnel, repair and stockage space, and other factors. Annual expenses will occur for repair parts, replenishment of spares, transportation, labor, maintenance of equipment and facilities, and other cost elements.

In this thesis, LSC is divided into Initial Investment and Annual Recurring Costs. These costs are further subdivided into the following cost categories:

a) Maintenance manpower.

b) Test and support equipment.

c) Inventory.

d) Training.

e) Transportation.

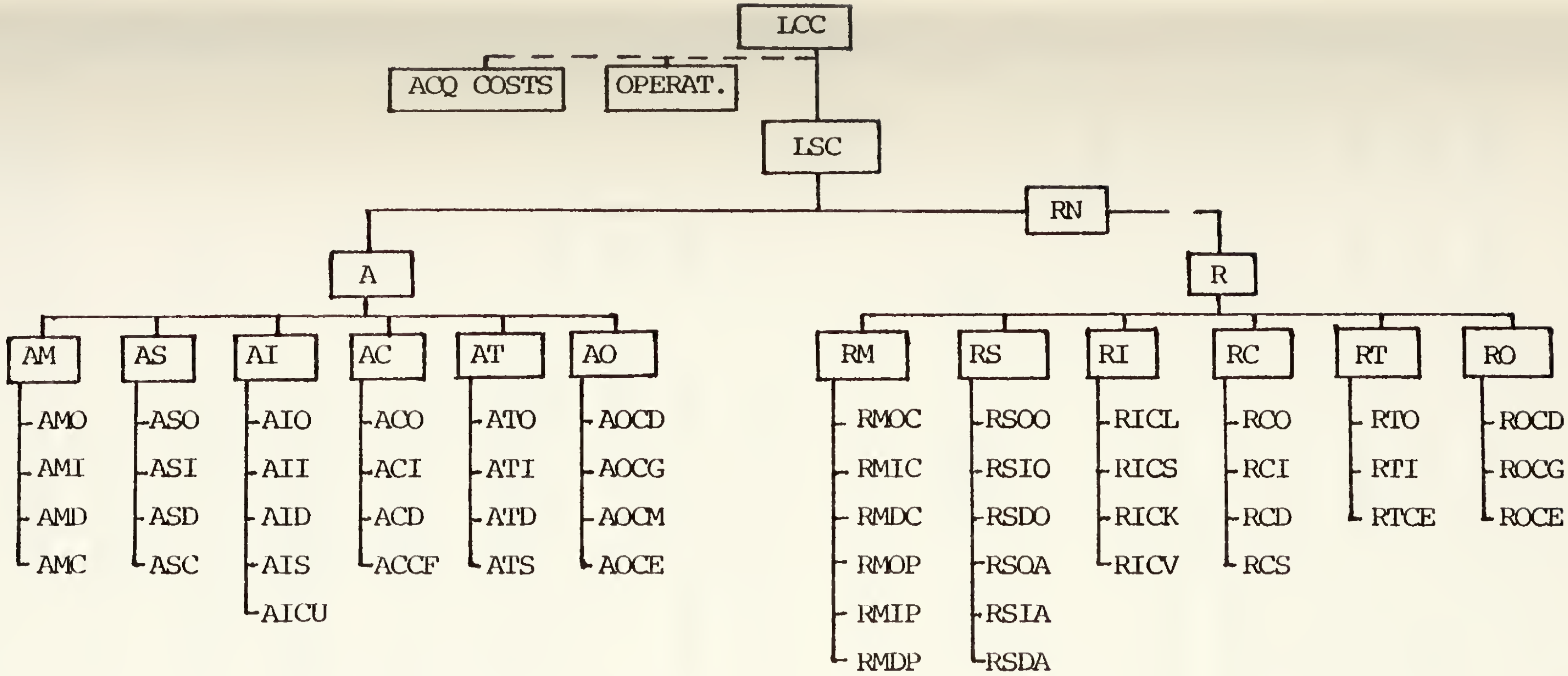
f) Other costs.

In the following, it is assumed that a module is repaired at failure. If a discard policy is chosen, the formulas to be developed will be modified, as discussed in Chapter IV.

The breakdown of the cost categories listed above is illustrated in Figure 3-3. Formulas for the cost elements are developed in the following sub-sections. Only cost elements which normally are to be considered in any estimate of the LSC for a system already designed will be considered. For evaluation of the LSC of another system, some of the cost elements may not be relevant or it may be necessary to include other expenditures.

3.3.1. Maintenance Manpower Costs

Maintenance manpower costs are broken down into compensation and other costs. Compensation costs include all



Abbreviations:

First Letter:

A: Investment costs
R: Annual recurring costs

Second Letter:

M: Manpower
S: Test & Support equipm.
I: Inventory
C: Training
T: Transportation
O: Other costs
N: Total for the life cycle

Third Letter:

O: Organizational level
I: Intermediate level
D: Depot level
C: Common/all sites
S: Stockage sites

Fourth Letter:

A: Common
C: Corrective maintenance
D: Documentation
E: Other costs
F: Equipment
G: Space
K: Consumables and materials
L: LRU's
M: Meetings
O: Peculiar items
P: Preventive maintenance
U: Entering cost
V: Holding cost

Figure 3-3. LSC Breakdown

direct costs associated with a particular billet and must be calculated for all levels of the support organization.

At the organizational level, manpower demand includes time spent on fault isolation, removing and replacing failed LRU's, and additionally a time to obtain tools and test equipment, time for paperwork, etc., the sum of which may exceed the active repair time several times. Time must also be allowed for preservation of obtained technical skills and for preventive maintenance. The equation for the annual costs (RMO) is:

$$RMO = \left\{\frac{f \cdot 365}{MTBF} \times (ARTO + ATO) \times HRO + PTT \times HRO\right\} \times NS$$

where:

f = Average operating hours per day;

MTBF = Mean time between failures;

ARTO = Active repair time per failure;

ATO = Average time associated with a repair task, including access, hookup of support equipment, paper work, packaging of failed items, etc.;

HRO = Hourly rate for maintenance personnel at the organization level;

PTT = total number of hours per year spent by maintenance personnel upon preventive maintenance, tests, and periodic checks.

NS = number of systems

In some instances, the formula for RMO must be modified. If the system is operated at a location isolated from other military establishments and required to

operate 24 hours per day, a minimum number of technicians must be assigned to the organizational level. On the other hand, if the system is onboard a ship or installed in an aircraft, a pool of maintenance personnel may be available already. If not fully utilized, this pool may be able to perform the additional tasks associated with a smaller system.

At the intermediate and depot levels a pool of maintenance personnel exists, which makes the estimate of the number of manhours required per year a little easier. The amount of labor needed is determined by the level of repair policy. For the case where LRU's are repaired at intermediate level and SRU's at depot level:

$$RMI = \left(\sum_{i=1}^{\ell} \frac{f \cdot 365}{MTBF_i}\right) \times (ARTI + ATI) \times HRI \times N_i$$

$$RMD = \left(\sum_{j=1}^{k} \frac{f \cdot 365}{MTBF_j}\right) \times (ARTD + ATD) \times HRD \times N_j$$

where:

RMI,RMD = Annual labor costs of corrective maintenance at intermediate level and depot level, respectively;

ℓ = The number of LRU types in the system;

k = The number of SRU types in the system;

MTBF = Mean time between failures;

HRI,HRD = Intermediate/depot level labor rate (inclusive overhead which is discussed below);

N_i = The total number of LRU_i in all systems;

N_j = The total number of SRU_j in all systems.

In addition to the manhours required at the workshops, occasionally assistance for the organizational level may be required. If so, not only the active repair time but the total time including traveling and delays should be used in the computation of manpower costs.

In some instances, the computation of manhour rates should be based upon the ratio of annual economic cost to manhours per year per man available for the maintenance tasks.

"Other Manpower Costs" include overhead costs assignable from supporting staffs, social security tax, bonuses, special pay for aircrews, allowance for quarters, retirement costs, administrative services, medical service, etc. Each element of "other costs" may be small, but added together they will account for between 20 and 40 percent for officers and civilians and between 30 and 50 percent of the annual billet cost for enlisted personnel [Ref. 10]. The exact percentage for each service and each paygrade can be obtained from historical data.

In summary, the equation

$$\begin{pmatrix}\text{cost of}\\ \text{maintenance}\\ \text{labor}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{maintenance}\\ \text{actions}\end{pmatrix} \times \begin{pmatrix}\text{manhours}\\ \text{per}\\ \text{action}\end{pmatrix} \times \begin{pmatrix}\text{cost}\\ \text{per}\\ \text{manhour}\end{pmatrix}$$

will grossly underestimate the maintenance manpower costs unless:

a) checks, tests, preventive maintenance, and all other tasks requiring maintenance personnel are included,

b) manhours per action cover the total number of hours associated with the action, which in general will be significantly greater than the direct repair time,

c) the cost per manhour is computed by dividing the annual billet cost of the person involved by the actual number of hours per year that the technician is available for maintenance tasks, and the appropriate value of "other maintenance costs" per hour is included in the labor rate.

In this thesis, "cost per manhour" allows for all these elements.

3.3.2. Test and Support Equipment Costs

The scheduled and unscheduled maintenance tasks of the repair cycle require maintenance stands, tools, and checkout and calibration equipment. Test and support equipment (TSE) can be classified as "standard" (items already in inventory) or as "peculiar" (items peculiar to the system under consideration). Lack of TSE will increase the turn-around-time of a failed item and reduce system effectiveness.

The investment costs of peculiar TSE (ASCO) are the sum of the investments for organizational level (ASO), intermediate level (ASI), and depot level (ASD), or

$$ASCO = \underset{\sim}{ASO} + \underset{\sim}{ASI} + \underset{\sim}{ASD}$$

Assuming that failed LRU's are removed and replaced, but not repaired at organizational level, the peculiar TSE needed at this level must always be procured, even when a

discard policy is chosen. The investment costs of peculiar TSE for intermediate level and depot level are determined by the repair policy chosen and by the number of repair actions.

The utilization rate of standard TSE determines if additional investment (ASCA) is required for this type of TSE.

Maintenance and support costs also occur for TSE. These costs could be estimated as for the primary system, but usually they are much more moderate costs, therefore, the annual support costs of TSE are normally predicted as a fraction (f_r) of the procurement costs.

The general formula for TCSE is:

$$\text{TCSE} = (\text{Investment costs}) + \left(\begin{array}{l}\text{Present value of the} \\ \text{annual recurring costs}\end{array}\right)$$

Investment cost + pec. TSE

$$= \text{ASCO} + \text{ASCA} + f_r \times (\text{ASCO} + \text{ASCA}) \times \text{NDF}$$

add. invest. cost

= discount fact

$$= (\text{ASCO} + \text{ASCA}) \times (1 + f_r \times \text{NDF}),$$

where NDF is the discount factor for the life cycle. Discount factors (DF) are computed in this thesis as: [Ref. 11]

$$\text{DF} = \frac{1 - (1+d)^{-Y}}{d}$$

where:

d = the discount rate;

Y = the number of years for which DF is computed.

3.3.3. Inventory Costs

As discussed in Section 3.2.2, the achieved system effectiveness is determined, for a given value of system MTBF, by the mean system downtime, which again is heavily affected by the probability of spares being available. The cost of spares for a military electronic system is significant and may account for as much as fifty percent of LSC [Ref. 12].

The total cost of inventory will be divided into:

(a) initial procurement of spares and repair parts,

(b) replenishment spares,

(c) other inventory costs.

3.3.3.1. Initial Procurement

This cost element is the one time expenditure to insure adequate support of the newly deployed systems over a specified interval of time.

Assuming that the repair policy is chosen, that MTBF's are known, and that the time elements in the equation (Section 3.2.1) for system mean downtime are set at the average values, the objective is to minimize this cost element. For example, suppose that the choise is among the following repair policies:

(a) all modules are repaired at intermediate level or discarded at failure.

(b) LRU_i is repaired at intermediate level, some of or all its SRU's are repaired at depot level, the rest discarded or repaired at intermediate level.

(c) all LRU's and SRU's are repaired at depot level.

Then, the following procedure can be used:

a) Assume that all repair parts for SRU's are available when needed and no initial procurement of LRU's and SRU's takes place. Check if the required system availability (A_o) has been reached. If not, continue.

b) For each repair policy, compute for each LRU the marginal return on investment (increase in A_o per \$ invested) if procured for the organizational level, and for each LRU and each SRU calculate the marginal return on investment for the other stockage policies possible.

c) The spare which provides the highest return on investment is purchased. The new value of A_o is computed and checked against the required value. If A_o is still too low, the spare with the highest return on investment, given previous procurements, is purchased next and so on, until the required value of A_o is achieved.

d) For each repair policy compute the minimum initial investment in spares and the associated stockage policy based on c).

When the least cost support alternative is determined, the cost of the stockage policy, as obtained above, will be added to all other cost elements of the repair policy with which it is associated.

A detailed procedure (called OPUS-VII) for initial procurement of spares is found in Appendix C.

The assumption that all repair parts necessary for repair of SRU's are in stock simplifies the

procedure. It is based on the assumption that this is the least expensive solution and the fact that an LSC model, useful for predictions only would be much more complicated without this simplification.

3.3.3.2. Replenishment Procurements

Replenishment spares and repair parts cost dominate the annual cost of keeping an inventory at a specified level (Section 3.3.1). The initial procurement is the minimum amount of spares and parts in inventory. Therefore the first replenishment procurement must take place immediately, and a cost occurs during the first year of the life cycle. However, it is assumed that no replenishment will be purchased during the last year (the procurement lead time).

For every LRU/SRU discarded at failure, a new one is purchased. If the total number of a replaceable unit (RU) in all systems is N and the MTBF of this item is $MTBF_a$, the average annual investment will be

$$TCD(RU) = \frac{365 \times f \times N}{MTBF_a} \times \binom{\text{unit}}{\text{cost}}$$

Average annual Investment

which, summed for all discarded RU's gives the average annual replenishment cost of discarded items.

When repair is attempted, a certain fraction (F) of the RU's will have to be condemned (because of damage under handling or transportation, for example) and replacements will have to be purchased. The value of F is difficult to predict and is usually based upon experience or engineering judgement.

The average annual replenishment costs for repaired RU's will therefore be

$$RI = TCD \times F.$$

The annual cost of repair parts is found quite analogously with the cost of discarded RU's as

$$\sum_{i=1}^{n} \begin{pmatrix} \text{total} \\ \text{number} \\ \text{used} \end{pmatrix}_i \times \begin{pmatrix} \text{unit} \\ \text{cost} \end{pmatrix}_i$$

where n is the number of different repair parts.

3.3.3.3. Other Inventory Costs

Other elements of inventory costs will also arise. Those having the greatest impact on LSC are:

a) Ordering Costs, the costs of processing an order through the purchasing and other departments. Included are labor costs, the cost of eventual computer time to update records, paper, postage, and telephone costs. This cost element may depend on the quantity procured and usually differs from one inventory system to another. For prediction of LSC an average value based upon historical data is normally used.

b) Inventory Management Costs, the management costs associated with entering and maintaining an item in inventory. It includes the costs of identification, description, editing and updating of data records, and computer time. These costs will differ from one supply support organization to another.

For cost estimation purposes, average values of entering cost per item and annual recurring management costs are used.

c) Inventory Carrying Costs, the costs associated with operating the warehouses and other stockage facilities, including the cost of direct labor, the annual costs of warehouse equipment, light, heat, insurance, breakage, obsolescence, and maintenance of facilities. Additionally, there is usually an opportunity cost incurred by having capital tied up in inventory. Even if this cost is not accounted for by the military, it is a cost for the government.

d) Stockout Costs, the costs of being out of stock when a demand occurs. These are extremely difficult to measure, especially in the military, but are included in some Life Cycle Cost models. In the U.S. military several different values (up to $1500) are used [Ref. 13].

e) Transportation and Receiving Costs, the costs of getting the material from the manufacturer to the central warehouse and to the proper storage location in the warehouse. Sometimes the cost of getting the order from the source of supply to the stocking facility is paid by the customer. If so, this cost is considered a part of inventory costs. The cost of transporting an item between military facilities is usually included in Transportation Costs.

The receiving costs cover inspection, testing, quality control, and record keeping.

Most of the cost elements discussed under "Other Inventory Costs" are affected by the support

organization and by the operating doctrine for the inventory system. In addition, some of the elements are difficult to measure. Sophisticated models, stochastic as well as deterministic, are described in the literature. But, for reasons of simplification, most models for prediction of LSC use two average values only; an item entering cost and an annual recurring inventory cost per item, which compensate for the Other Inventory Costs.

3.3.4. Training Costs

For the computation of the maintenance manpower needed for the support of the system, it was assumed that the technicians possess the skills necessary to get the jobs done. The life cycle training costs are normally allocated to (a) training equipment, (b) initial training, and (c) recurring training.

a) The training equipment consists of training systems, operating units, manuals, guides, texts, training aids, special installations, facilities, and other training material not included in the procurement contract.

b) Initial training costs consist of all initial costs of training maintenance personnel. These costs will typically include such items as trainee and instructor salaries, per diem, and travel expenses. The costs may be divided to identify training expense for various levels of maintenance, or for each level of the maintenance organization.

c) Recurring training costs are generated by the requirement to replace personnel who are reassigned, or who retire

from positions requiring special training for the system to be maintained.

The training costs' part of an LSC may be expressed as:

$$TTRAIN = ACCF + AC + ft \times AC \times NDF = ACCF + AC(1 + ft \times NDF)$$

where:

$TTRAIN$ = life cycle maintenance training costs;

$ACCF$ = costs of training equipment and materials;

AC = initial training costs;

ft = the fraction of trained personnel to be replaced per year;

NDF = normal discount factor.

As mentioned above, AC is a function of training hours required (H), hourly rate for involved personnel (HR), and an overhead factor (OH) covering instructor salary, per diem, and other expenses. The hourly rate and the number of trainees are affected not only by system design and characteristic, but by the maintenance policy chosen as well. The formula for TTRAIN is:

$$TTRAIN = ACCF + (1 + ft \times NDF) \times \sum_{i=0}^{\ell} H_i \times HR_i \times OH$$

where:

ℓ = the number of levels of the maintenance organization (including logistics staff);

H_i = total training hours required for this level;

HR_i = average hourly rate at this level;

OH = overhead factor ($OH \geq 1$).

3.3.5. Transportation Costs

Transportation costs occur when items are shipped for repair or replacement. The general way LSC models deal with these costs is to compute the number of assemblies expected to be shipped, and multiply this by a transportation cost factor, determined through cost estimating relationships based on module size and weight, organizational characteristics, and transportation method.

The number of assemblies to be shipped (NA) from the organizational level per unit of time is a function of the number of systems in operational use (NS), the system MTBF, the fraction (F_ℓ) of failed items repaired locally, and system application factor (f):

$$NA = \frac{NS \times f}{MTBF} \times (1 - F_\ell)$$

This element of LSC usually cannot be predicted with any degree of accuracy unless a detailed knowledge of the organization, the maintenance, and the stockage policy is available. Fortunately, the transportation costs normally account for less than five percent of the total LSC and the estimating procedure described above may be usable. If not so, a detailed analysis may pay off.

The transportation times between system level and intermediate or depot level, between intermediate and depot level, and between stockage facilities and each level of the maintenance organization are all variables in the formula for system mean downtime ($\overline{MDT}$) per failure and will, therefore, affect system effectiveness and/or the initial procurement of spares. Trade-off possibilities between transportation costs and other elements of LSC will exist. A more expensive mode of transportation may lead to a reduced total LSC.

3.3.6. Other Costs

Many other sources of costs affecting LSC exist. These must be evaluated as to their significance in each procurement, and judged to be included or not in the estimate of LSC. Some of the common sources are:

a) Documentation and Data costs: For a system in its development phase, this cost is estimated on the basis of the number of pages required for each item of equipment for different repair options. It includes the costs of writing, editing, reproduction, assembling, packaging, and shipping. For a system already in operational use elsewhere, the cost per technical manual is known. The total documentation cost for each maintenance policy can be estimated as the sum of the documentation costs for each level of the support organization.

b) Space and Facilities costs: A system may require new facilities for testing, maintenance, and warehousing/stockage.

If so, the cost of investment, modification, operation, and maintenance of these facilities should be included in LSC.

c) Overhaul and Modification costs: For electronic systems overhauls and modifications are expected. The predicted costs include labor, overhead, round-trip transportation, and material. Replacement and modification of common and peculiar support equipment may be included.

d) Discount and Inflation Factors (see Section B.3.2.).

e) Obsolescence or Salvage cost: A termination cost may be expected. If a salvage value is anticipated, this may be accounted for as a negative cost.

3.4. MINIMUM LIFE SUPPORT COSTS

Computation of LSC for each maintenance policy can be accomplished only after the complete model has been developed. The least cost alternative can be determined, as shown in Figure 3-4.

The spectrum of maintenance policies may include:

A = All LRU's discarded at failure;

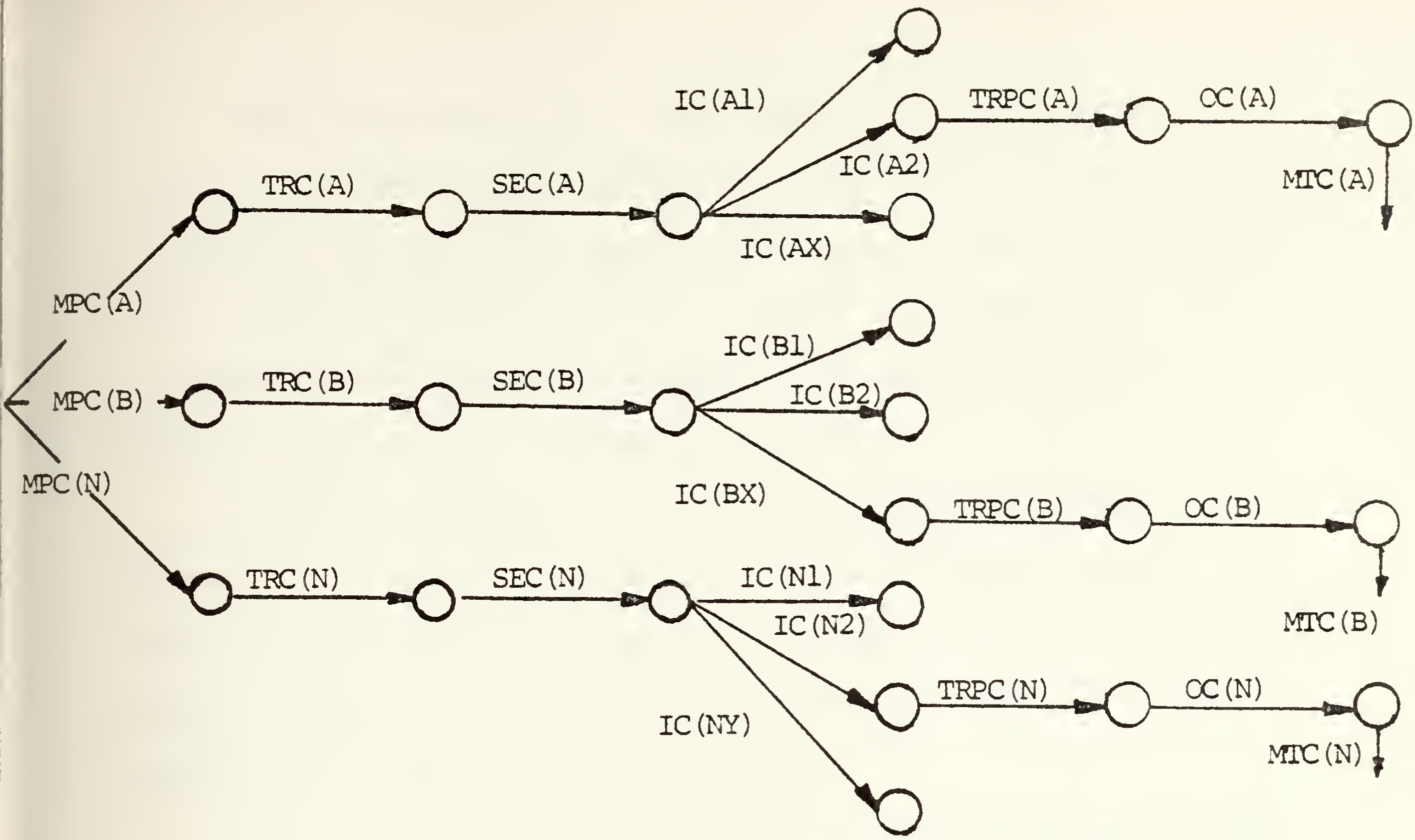
B = All LRU's repaired at intermediate level, all SRU's discarded at failure;

⋮

N = All LRU's and all SRU's repaired at depot level.

The least LSC of each alternative is computed as (referring to Figure 3-4):

$$MTC(I) = MPC(I)+TRC(I)+SEC(I)+IC(IJ)+TRPC(I)+OC(I)$$



In this figure, the following abbreviations are used:

MPC(I)	=	Maintenance manpower costs of policy I;
TRC(I)	=	Training costs of this alternative;
SEC(I)	=	Costs of test and support equipment;
IC(I,J)	=	Inventory costs, maintenance policy I and stockage policy J;
TRPC(I)	=	Transportation costs of this alternative;
OC(I)	=	"Other Costs" associated with this alternative;
MTC(I)	=	Minimum LSC for this maintenance and stockage policy.

Figure 3-4. Determination of Minimum LSC

The alternative with the lowest value of MTC(I) is, from a purely economical point of view, the preferred one and is normally called "The Least Cost Alternative." Each element of LSC is computed using a number of assumptions, and is combined with other cost elements in such a way that the required system effectiveness is achieved.

Trade-off possibilities exist, expecially between the two main cost drivers, inventory and maintenance costs. Unless sufficient attention has been paid to these possibilities, a great number of solutions, cheaper than "The Least Cost Alternative," may never be discovered.

To evaluate LSC of alternative systems and to perform trade-off analysis, a computerized model is required. Two such models are used for the numerical example in Chapter VI. These models are described in Chapter V. AIR is an LSC and LOR (Level of Repair) model used by the US Navy. SIMPLE was programmed by the authors and is based on the equations developed in this chapter. This model does not have the capability to compute the initial procurement and allocation of spares. The OPUS-VII model (Chapter V) is used for this purpose and its output is used as input in SIMPLE.

IV. REPAIR VS. DISCARD DECISIONS

4.1. INTRODUCTION

The optimum level of reapir (LOR) of a system can be determined following the procedure described in Chapter III. The next question is, "should the failed item be repaired, or is it more economical to throw it away?" The decision to repair or to discard-at-failure can have a very strong impact on the life support cost of a complex system of hardware. The Vendor Repairable Items Panels of a joint Aerospace Industries Association and Electronic Industries Association Spare Parts Committee [Ref. 14] estimated that an overall saving as great as 30% may be realized if the proper decisions are made.

Other studies disclose that most organizations, especially military, tend to prefer the repair posture because they are reluctant to throw away "valuable" items or have underestimated the cost of repairs.

Besides the economic benefits, many other advantages may be obtained from a discard-at-failure alternative. From a design viewpoint, a module that is to be discarded at failure is simplified in that no provisions for repair need to be made. Other technical options can reduce weight, provide for dust- or water-proofing, simplify the packaging, improve reliability, and reduce technical data requirements. From an operational point of view, an advantage is a reduced need to deploy sophisticated test and support equipment and skilled technicians.

Furthermore, a discard design normally results in a lower time to restore a failed system, and a throwaway assembly can generally be designed to be produced at a lower cost than if designed for repair.

4.2. THE REPAIR/DISCARD DECISION

Repair/discard analysis normally concentrates on the economic impacts resulting from the decision.

For a repair policy, the events that take place and their associated costs are described in Chapter III. Under a throwaway policy, after a failure has occurred a replacement unit is obtained, and the failed item is replaced. If necessary, a reorder action is taken. As described in more detail below (Section 4.3) the economically preferable policy is obtained by comparing the total costs of the repair and the discard alternatives, and by choosing the one having the lower cost.

Military considerations, technological constraints, and planned system deployment represent some of the additional considerations that should also be included and evaluated. Such elements must be evaluated on a case by case basis by the user.

There are many points in the life cycle where a repair/discard decision may take place. In a study, Criteria for Repair vs. Discard Decisions, the Logistic Management Institute [Ref. 15] identified five major decision points in the system life cycle (Figure 4-1).

The earlier in the life cycle that the repair/discard decision is made, the higher are the potential savings.

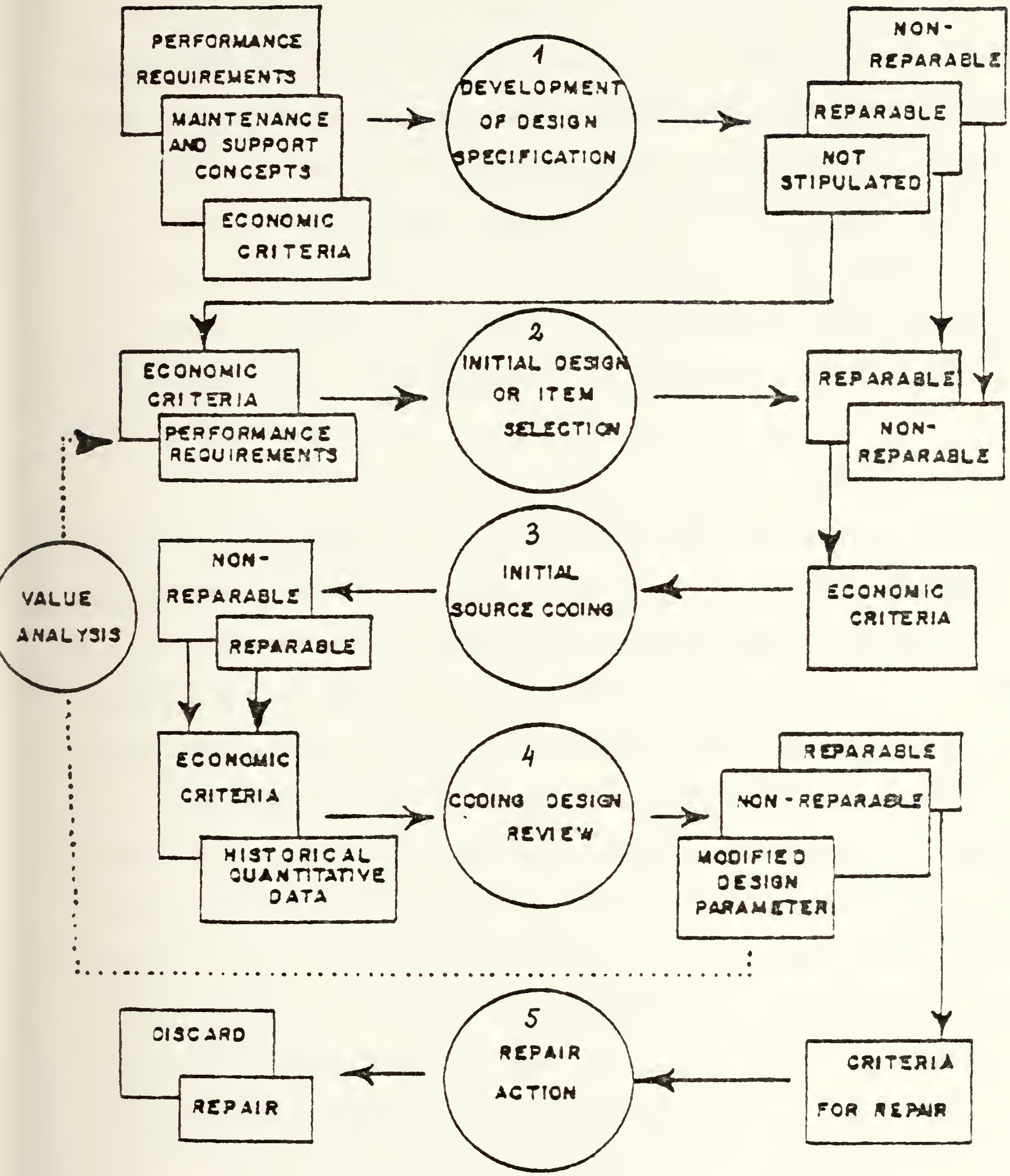


Figure 4-1. Repair vs. Discard Decision Points

Unfortunately, some of the cost elements of importance for the decision are sensitive to variables which are difficult to predict in the early stages of the life cycle, unless the item is one which represents a well-known technology and experience is available regarding the characteristics of the item. The ability to accurately predict costs associated with repair and discard actions improves later in the life cycle. In addition, after the equipment has been produced, the unit cost and the failure rate are known, and alternative designs have been eliminated. This generally reduces the scope of the decision process.

During the Use Period, actual values are obtained for the parameters on which the original repair/discard decision was based. Economic advantages may be obtained by changing the decision if, for example, the MTBF or the unit cost of a module differ significantly from the expected values. Therefore, even when an item is designed as repairable, the user may decide to discard it at failure. This decision may be made before the initial provisioning of spare parts is decided upon or it may be postponed until some field experience is obtained. The final point of decision occurs when the assembly actually fails. If the item is coded as a repairable, a decision must be made based on the unit cost and the extent of the damage to the item under consideration.

4.3. A SIMPLIFIED REPAIR/DISCARD MODEL

A variety of Repair/Discard models are available. These models are economic decision models in which the cost of

repairing an item is compared with the cost of discarding it at failure. The costs considered are total life-cycle costs, which often makes the models quite complex. According to the degree of complexity, the repair/discard models can be divided into the following three groups [Ref. 5].

a) Total Cost Models--computing the exact costs of the repair as well as of the discard alternative.

b) Delta Cost Models--computing the difference between the repair and discard alternative, thus eliminating from the difference equations identical terms of the repair and discard costs.

c) Simplified Models--eliminating cost factors and terms which are relatively insignificant or insensitive to the decision.

The intent of this chapter is to develop a simplified delta cost repair vs. discard decision model. As in the rest of this thesis, attention is directed towards equipment already designed, which simplifies the difference equations. Furthermore, in order to be able to compare the results with those obtained from AIR, fixed values for some readily estimated parameters are used to develop a simple "screening rule" and to highlight the more important factors which should be considered.

The optimal policy for each module is determined by using the following general equation:

$$\Delta C = LSCR - LSCD$$

where:

LSCR = the total life support cost of the equipment if the module is repaired at failure;

LSCD = the total life support cost of the equipment if the module is discarded at failure.

ΔC is the difference in total support cost between the two maintenance policies with a positive difference indicating that a discard policy is more economical, and a negative difference indicating that the repair alternative is preferable.

Values of LSCR and LSCD to be developed in this chapter will be based on the Life Cycle Support costs as described in Chapter III. Therefore, the formulas to be developed can only be used for repair/discard decisions for modules already designed and not as a tool in the earlier phases of the life cycle. Further, for reasons of simplification, cost elements judged to have an insignificant impact upon ΔC are omitted.

In accordance with Chapter III, ΔC can be obtained as

$$\Delta C = \Delta C1 + \Delta C2 + \Delta C3 + \Delta C4 + \Delta C5 + \Delta C6$$

where:

$\Delta C1$ = difference in maintenance manpower costs;

$\Delta C2$ = difference in test and support equipment costs;

$\Delta C3$ = difference in inventory costs;

$\Delta C4$ = difference in training costs;

$\Delta C5$ = difference in transportation costs;

$\Delta C6$ = difference in other elements of LSC.

For reasons of simplification, it is assumed that

-- Items designed for discard at failure are not ever considered for reapir.

-- When the system fails, the failure will be located to a specific Line Replaceable Unit (LRU), which will be removed, replaced, and sent to intermediate level for repair, if it is to be repaired, by replacing the failed Shop Replaceable Unit (SRU). The SRU, if it is to be repaired, is repaired at depot level. (The formula can easily be modified to fit any other maintenance alternative.)

-- Low cost assemblies are discarded at the organizational or intermediate level, and high value assemblies are discarded at the depot level only.

-- Average values per year are used for all recurring costs.

4.3.1. $\Delta C1$, Maintenance Manpower Costs

The cost of preventive maintenance is unaffected by the repair/discard decision, and the value of $\Delta C1$ per failure is the difference between the cost of corrective maintenance and the discard cost.

Under the assumptions stated above, the discard alternative will reduce the time for paperwork and eliminate the packing and other time elements for low cost items at intermediate level. If HRI is the hourly rate for personnel at this level and the total reduction in time per failure is RTI, the saving per failure is HRI $\times$ RTI. At depot level, no

time will be needed in this case. The result is a saving of $TTD \times HRD$, where TTD is the average total time per repair at depot for this item and HRD is the hourly rate for depot personnel.

For a high cost item discarded at failure at the depot level, time will not be used for fault isolation, replacement of failed parts, packing, and some of the paperwork. If RTD is the time reduction per failure, the saving is $RTD \times HRD$. The savings per failure for the discard policy are, for a high cost item,

$$SPFH = RTD \times HRD.$$

The savings per failure for the discard policy for a low cost item are:

$$SPFL = RTI \times HRI + TTD \times HRD.$$

The annual number of failures of an assembly is

$$ANF = \frac{N \times f \times 365}{MTBF}$$

where:

N = The number of systems procured multiplied by the number of this item per system;

f = Average operating hours per day;

MTBF = Mean time between failures (hours).

For the total life cycle $\Delta C1$ becomes,

$$\Delta C1 = SPF \times ANF \times NDF$$

where NDF is the normal discount factor (as defined in Section 3.3.2.).

4.3.2. $\Delta C2$, Test and Support Equipment Costs

Normally, the costs of common support equipment will not be affected significantly by a repair/discard decision and the delta cost of common support equipment can be assumed to be zero.

If a discard alternative is chosen after the system has been in use for a period of time, the only change is the cost of peculiar support equipment. If its value is CPSE when repair is performed and zero under discard, it follows that

$$\Delta C2 = CPSE \times F \times RD \times X$$

where:

CPSE = Acquisition cost of test and support equipment peculiar to this assembly;

F = Annual support ratio for the equipment (the ratio between annual support cost and investment);

RD = Discount factor, computed for the remaining part of the life cycle (Section 3.3.2.);

X = The total number of this type of support equipment.

If a discard alternative for a specific item is chosen during the acquisition period, the maximum savings are obtained because procurement of peculiar support equipment can be avoided. In this case

$$\Delta C2 = CPSE \times X \times (1 + F \times NDF)$$

4.3.3. <u>ΔC3, Inventory Costs</u>

In accordance with Chapter III, $\Delta C3$ will be computed as $\Delta C3 = \Delta C31 + \Delta C32 + \Delta C33$, where:

$\Delta C31$ = Difference in initial procurement costs;

$\Delta C32$ = Difference in replenishment procurement costs;

$\Delta C33$ = Difference in other inventory costs;

As demonstrated in Chapter III (and Appendix C), for the repair alternative, the initial procurement of spares can only be determined for a given system availability and for the total mix of spares.

An approximation to the number (NN) of a given item to be procured can be obtained from the formula

$$P \leq \sum_{x=0}^{NN-1} \left(e^{-\frac{N \times TAT \times f}{MTBF}} \times \frac{\left(\frac{N \times TAT \times f}{MTBF}\right)^{x}}{x!} \right)$$

where:

P = The probability that the spare is available given a demand;

N = The number of systems multiplied by the number of this SRU/LRU per system;

TAT = The turnaround time (hours) for this item;

f = Operating hours per day.

Depending upon the procurement lead time, it may be sufficient initially to buy spares for one year if the item is discarded at failure. To obtain a high probability that a spare is available when a demand occurs, a more expensive approach is chosen, which is to buy enough spares for two years (although the lead time is assumed to be one year). The resulting value of $\Delta C31$ becomes

$$\Delta C31 = NN \times UC - 2 \times \frac{365 \times f \times N}{MTBF} \times UC$$

where UC is the unit cost.

When a repair policy is preferred, a certain fraction (Fr) of the failed items will be condemned. The annual cost of the replenishment procurement will be

$$\frac{365 \times f \times N}{MTBF} \times Fr \times UC.$$

Each repair requires a certain number of subunits and repair materials. The average cost of such materials is generally estimated as a fraction (MR) of item unit cost or

$$\frac{365 \times f \times N}{MTBF} \times (1 - Fr) \times UC \times MR$$

The total annual costs under a repair policy are then

$$\frac{365 \times f \times N \times UC}{MTBF} \times [Fr + (1 - Fr) \times MR]$$

The corresponding cost of the discard alternative is

$$\frac{365 \times f \times N}{MTBF} \times UC$$

For the life cycle the result is

$$\Delta C32 = \frac{365 \times f \times N \times UC}{MTBF} \times [Fr + (1-Fr) \times MR] \times NDF - \frac{365 \times f \times N}{MTBF} \times UC \times DR$$

where NDF is the normal discount factor and DR is the discount factor for the life cycle period minus the last two years, which are covered by the initial procurement.

The ordering costs and inventory management costs are higher for an assembly repaired at failure than the corresponding costs for the same assembly discarded at failure. The reasons for this are that repair parts must be kept in inventory and a cost occurs everytime such parts are requested. Normally, the additional life cycle cost for a repairable item can be expressed as

$$\Delta C33 = NPI \times IEC + NPI \times IRC \times NDF$$

where NPI is the number of sub-assemblies/parts entered into the inventory system, IEC is the item entry cost, and IRC is

the item retention cost. Values of IEC and IRC can be obtained from historical data or based upon Cost Estimating Relationships.*

The total value of ΔC31, ΔC32, and ΔC33 results in

$$\Delta C3 = UC \times [NN - \frac{365 \times f \times N}{MTBF} \times [2 + DR - \{Fr + (1-Fr) \times MR\} \times NDF]$$

$$+ NPI \times IEC + NPI \times IRC \times NDF.$$

4.3.4. ΔC4, Training Costs

The costs of training and training equipment may be lower if one or more items are discarded instead of repaired at failure. Although total training costs may be an appreciable part of LSC, the change is usually insignificant when only a single or a few modules of a system already in production are discarded instead of repaired at failure. When this is the case ΔC4 can be set equal to zero.

4.3.5. ΔC5, Transportation Costs

For a repairable assembly, the determination of this cost element may be based on cost estimating relationships using unit weight (UW) and transportation rate per pound (TR) established for the organization. The life cycle cost of transportation (TTRANS) may be expressed as

$$TTRANS = \frac{365 \times f \times N}{MTBF} \times UW \times TR \times NDF$$

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*"Cost Estimating Relationships (CER) are analytic tools that relate various cost categories to cost generating or explanatory variables. For instance, it may be feasible to relate life cycle cost in terms of unit weight, cost per unit of range, cost per maintenance action, ..." [Ref. 2].

where:

f = Operating hours per day;

N = The total number of the assembly installed in the system;

UW = The weight of the assembly;

TR = The appropriate transportation rate per pound;

NDF = Normal discount factor.

For the repairable units, transportation to and from the support source is considered. For the throwaway case, a one way cost is applicable, reducing TTRANS by 50%. Thus,

$$\Delta C5 = 0.5 \times \frac{365 \times f \times N}{MTBF} \times UW \times TR \times NDF$$

For low cost items stocked at the organizational level, ΔC5 will be twice as high.

For high cost items, discarded at depot level, ΔC5 is zero.

For some organizations, a more reliable estimate of ΔC5 can be obtained based upon average distances between the different levels of the support organization and an average cost per mile of transportation. The procedure resulting in the most accurate estimate should be used.

4.3.6. <u>ΔC6, Other Elements of LSC</u>

These elements include documentation and data costs, space and facilities costs, and overhaul and modifications costs. These cost elements are generally significant

to a repair/discard analysis but only when many items within a common category are considered as a single entity to a repair versus discard choice. If so, these costs must be included in the computations. Otherwise, $\Delta C6$ can be set to zero.

4.4. A NUMERICAL EXAMPLE

To obtain a simplified screening rule for the repair/discard decision, the delta cost equations (Section 4.3) are reduced by using representative values for some of the variables. The total number of a module in all systems (N), MTBF, and the unit cost of a module are used as parameters.

4.4.1. Numerical Values Used

The values used for the variables are:

a) HRI--20 $/hour (including overhead);

b) HRD--25 $/hour (including overhead);

c) RTI--0.8 hours per failure;

d) RTD--0.4 hours per failure;

e) TTD--1.2 hours per failure;

f) f--24 hours;

g) d--10%;

h) NY--15 years;

i) CPSE--$2500;

j) X--1;

k) F--0.1;

l) Fr--0.1;

m) MR--0.05;

n) NPI--10;

o) IEC--\$40;

p) IRC--\$50;

q) $UW \times TR$--\$6;

These values reduce the delta cost equations as follows:

4.4.1.1. $\Delta C1$, Maintenance Manpower Costs

For low cost items:

$$\Delta C1 = \$46 \times 7.6 \times 8760 \times N/MTBF$$

$$= \$3.1 \times 10^{6} \times N/MTBF$$

For high cost items:

$$\Delta C1 = \$10 \times 8.67 \times 8760 \times N/MTBF$$

$$= \$0.76 \times 10^{6} \times N/MTBF$$

4.4.1.2. $\Delta C2$, Test and Support Equipment Costs

Assuming peculiar test and support equipment is not procured,

$$\Delta C2 = \$2500 \times 1 \times (1 + 0.1 \times NDF) = \$4400$$

For the case where a discard alternative is chosen one year hence, $\Delta C2$ = \$1675.

4.4.1.3. Inventory Costs

$$\Delta C3 \simeq UC \times [NN - \frac{70{,}000 \times N}{MTBF}] + 4200$$

4.4.1.4. $\Delta C5$, Transportation Costs

$$\Delta C5 \simeq 200{,}000 \times N/MTBF$$

4.4.1.5. Total Delta Cost

For a low cost item for which peculiar test and support equipment is not procured:

$$\Delta C = 3.1 \times 10^{6} \times N/MTBF + UC \times [NN - \frac{70{,}000 \times N}{MTBF}] + 2{,}000{,}000 \times N/MTBF$$

$$+ 4{,}200 + 4{,}400$$

$$= 3.3 \times 10^{6} \times N/MTBF + UC \times [NN - \frac{70{,}000 \times N}{MTBF}] + 8{,}600$$

where NN is a function of MTBF, TAT, and N. Values of NN are found in Table 4-1 for TAT = 888 hours and P = 0.95.

Table 4-1

Values of NN

N	MTBF (hours)						
	1000	5,000	8,760	10,000	20,000	50,000	100,000
24	NN=28	8	6	5	3	2	1
48	NN=45	14	9	8	5	3	2
96	NN=86	26	15	14	8	4	3

In Figure 4-2, break-even points as a function of N, MTBF, and unit cost are presented. It should

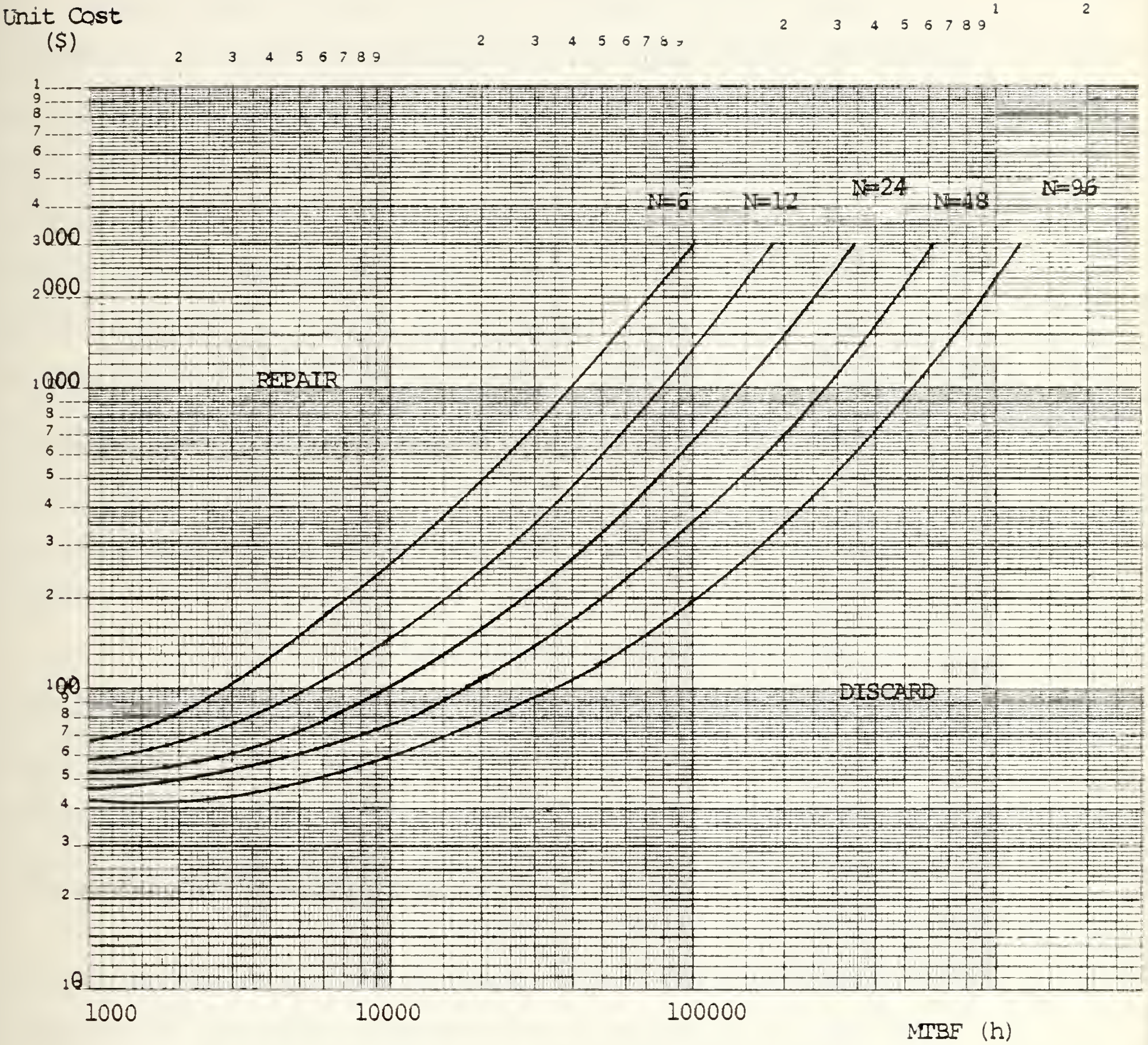

Figure 4-2. A Screening Rule for Repair/Discard Decisions for the Example Data

be remembered that these curves are valid only for the numerical values used in this section. Further, the graphs are computed for assemblies designed for repair and, therefore, don't include some of the most important advantages of the discard design. For modern electronic equipment, the relevant values of MTBF for a module may range from a few hundred to close to one hundred thousand hours. The repair/discard decision is sensitive to the quantity of the specific item maintained by the support organization, especially for high values of MTBF, but if few systems are supported by the support organization, the best alternative may be to discard items designed for repair, even when the unit cost is as high as $1000.

The curves in Figure 4-2 can be combined by using the expected number of failures during the life cycle for the specific type of module as the independent variable instead of MTBF. The result is a general screening curve, as illustrated in Figure 4-3. (The "solid" curve.)

To obtain an estimate of the sensitivity to the variables for which fixed values have been used, the break-even curves are computed for N equal to 24, and the following parameters changed, one at a time, as follows:

-- Labor rates reduced by 50 percent.

-- Peculiar support equipment procured before a repair/discard decision is made.

-- The turnaround time (depot level) reduced by 50 percent.

-- The number of repair parts per item reduced by 50 percent.

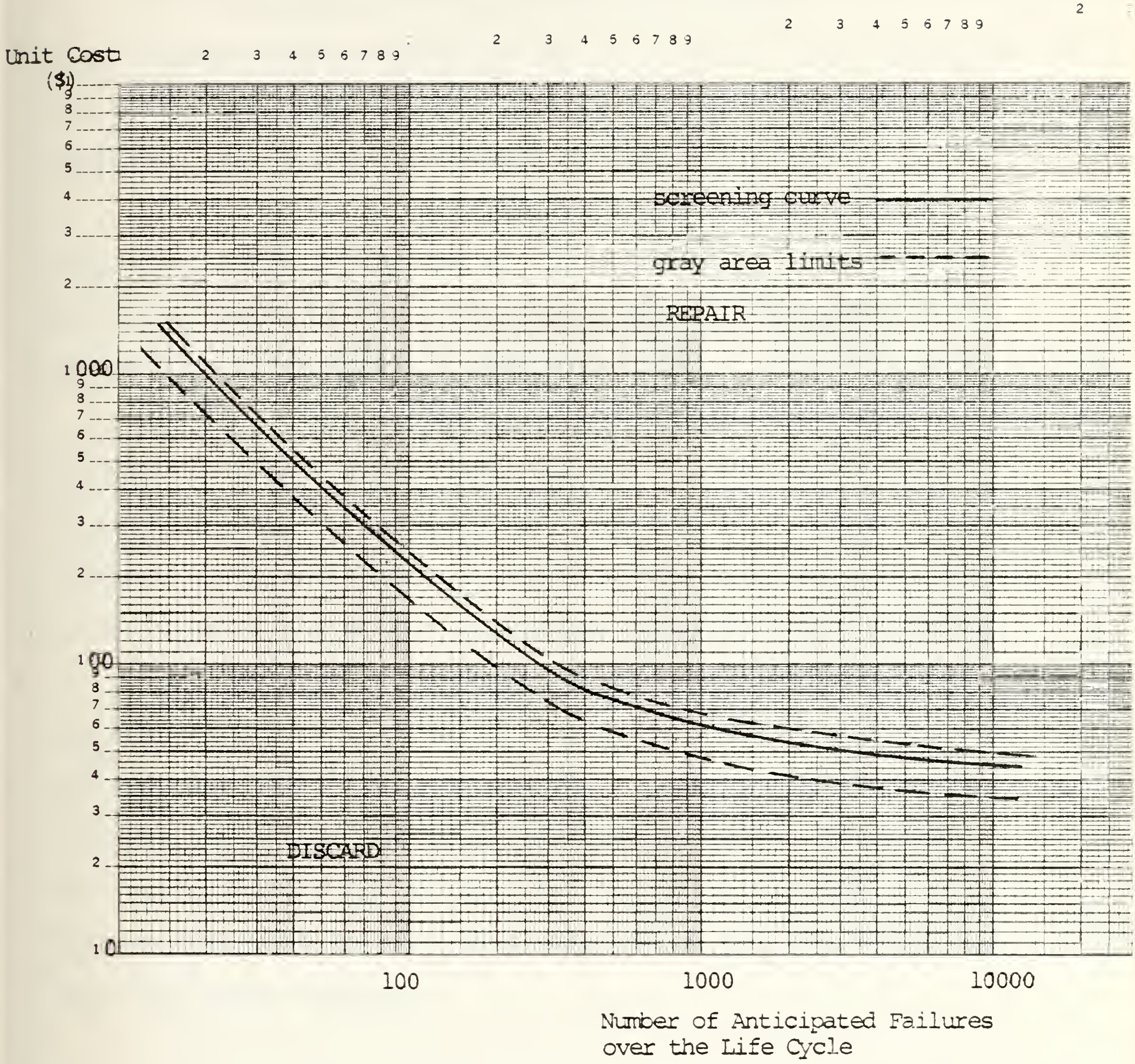

Figure 4-3. Screening Curve for Repair/Discard Decisions, Including "Gray Area"

-- The life cycle period increased by 100 percent.

-- The life cycle period reduced by 50 percent.

-- Discount rate reduced to zero.

The first five changes are favorable to the repair policy, while the last two are favorable to the discard policy.

The repair/discard decision is not heavily affected by any one of these variables. The maximum deviation caused by any of the variables is within the dotted curves, the "Gray Area," Figure 4-3.

The equations and the numerical example make it possible for items already produced for repair at failure, to base a repair/discard decision on a simple screening rule using the item unit cost and the expected total number of failures of the module during the life cycle as parameters.

A repair/discard model, based upon the equations developed in this chapter, has been computerized and included in SIMPLE (Section 5.4.). The results are compared to those obtained using the MIL-STD-1390B, AIR model for repair/discard decisions. For any value of MTBF, the maximum deviation in unit cost computed by the two models is less than seven percent.

V. MODELS USED FOR THE NUMERICAL EXAMPLE

5.1. INTRODUCTION

Many life cycle cost models have been developed. Most of the models reviewed are very complex, primarily because they are designed as "General Purpose Models," having the capability to deal with almost any type of equipment and to cover all phases of the system life cycle. Such models require a large amount of input data and their complexity makes it difficult for the user to understand them completely. The defense for a general purpose model is that the user can just ignore irrelevant input data, but to do so requires that the analyst understands the structure completely.

Two other types of models are Operating and Support Cost models and Life Support Cost (LSC)/Level of Repair (LOR) models, both of which exclude research and development and acquisition costs. Further, LSC/LOR models omit the costs associated with the operation of the system.

If a cost model is to be used to obtain the lowest possible life cycle cost, it must be adequate as a design tool. Since this thesis concentrates on systems already designed and the support costs of such systems, an LSC model is to be preferred. Four models, published as "Military Standard 1390B Level of Repair," are examples of LSC/LOR models. One of these, Naval Air Systems Command Equipments (AIR), is used for the numerical analysis in Chapter VI and is described in Section 5.2. The way in which AIR deals with initial procurement of

spares is found, for the purpose of this thesis, to be undesirable. An excellent model for this purpose, OPUS-VII, has been developed in SYSTECON AB, Sweden, and made available to the Naval Postgraduate School.* OPUS-VII is described in Section 5.3.

Realizing that not even the most complex LSC model can cover every weapon system acquisition process, that a simplified model would cover the requirements, and having discovered limitations in AIR, a model was developed (Section 5.4) based upon the equations found in Chapter III (LSC) and Chapter IV (Repair vs. Discard). This model is called SIMPLE.

5.2. THE AIR MODEL

A detailed description of AIR is enclosed as Appendix D. The cost equations used by the model are found in MIL-STD-1390B (NAVY), and instructions for how to use AIR are found in "AIR, User's Manual" [Ref. 16] and "AIR, Programmer's Manual" [Ref. 17].

The AIR model was designed for determination of the optimal level of repair policy, including the discard option, for each module of a system. The policy suggested for implementation defines either the maintenance level at which the repair action should be performed, or the discard actions that should take place.

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*OPUS-VII is a proprietary product of Systecon AB, Stockholm, Sweden.

5.2.1. General Description of AIR

AIR considers simultaneously all items of a system according to their arrangement in a part hierarchy illustrated by Figure D-1. Three levels of indenture are considered: Weapon Replaceable Assemblies (WRA) corresponding to LRU's, Shop Replaceable Assemblies (SRA) corresponding to SRU's, and SUB-SRA's which are the sub-assemblies necessary for repair of SRA's.

For each indenture level, four level of repair (LOR) alternatives are considered:

a) Intermediate (IMA) repair, equivalent to local (organizational level) repair;

b) Prime-Intermediate (PIMA) repair, equivalent to intermediate level repair;

c) Depot repair, and

d) Discard at failure.

Two major assumptions are used in the assignment of an LOR code: (1) The LOR coding of a WRA does not depend on which of its SRA's failed, and (2) an item can only be shipped to a level of repair higher than that for which its higher assembly is coded.

5.2.2. The Optimization Procedure Used by AIR

Life support costs are computed for each item, each LOR alternative, and different cost categories. Some of the costs allocable to an item depend on the LOR code of the item and on that of its next higher assembly. The optimization procedure is initiated by computing for each SUB-SRA the

optimal LOR assignment for all possible assignments of its SRA. The next step is to obtain the optimal assignment of each SRA. LSC of the SRA is available from step one. For each possible assignment of a WRA, the optimal assignment of each of its SRA's is found, considering both the cost of the SRA and the costs of the optimal assignment of its SUB-SRA's.

The final step is to find the optimal assignment of WRA's, taking into consideration the associated costs of its SRA's and SUB-SRA's.

The LSC for the WRA plus the sum of the optimal costs for its SRA's and SUB-SRA's is computed for each of the LOR alternatives (Section 5.2.1.). The smallest of these costs determines the LOR code for the WRA and its sub-units.

5.2.3. Computation of LSC

AIR allocates costs to six major categories:

a) Inventory;

b) Support equipment;

c) Space;

d) Labor;

e) Training;

f) Documentation

All cost computations are based upon formulas included in MIL-STD-1390B(NAVY). The more important of the formulas are included in Appendix D. Therefore, only a brief discussion of problem areas is found in the following sections.

5.2.3.1. Inventory Costs

AIR computes inventory costs as the sum of Repairable Inventory Costs, Repair Scrap Costs,

Inventory Administration Costs, Repair Material Costs, and Transportation Costs.

As demonstrated in Section 6.6.1.1., the calculation of the repairable inventory quantity is one of the weaker parts of the model. Based upon a required number of days of stock, and for operational sites a safety period to cover excess demands, an inventory quantity is computed for each site. The objective is to provide a 95 percent confidence level against stock-out at the operational site; a measure of effectiveness which is not directly relatable to system effectiveness (Section 2.1.1.). Furthermore, the computation of inventory levels is based on a Poisson arrival distribution of demands, but approximations are used, underestimating the quantity of spares needed. Finally, the per site quantity of each item is a function of unit cost; the higher the unit cost, the lower is the quantity. The rules for computation of repairables inventory are found in Section D.3.2.

5.2.3.2. Labor Costs in AIR

AIR underestimates the cost of manpower. The labor costs are computed as the cost of manhours required to fault isolate and to replace the failed item (MIL-STD-1390B, page 2). No time is included for getting tools and documentation, for cleaning, for packaging the failed item, and for other administrative duties. The sum of these time elements will usually be several times higher than the active repair time.

AIR does not include any time for preventive maintenance or periodic checks and adjustments performed by maintenance technicians.

Finally, the labor rate used by the Navy ($10 for IMA and PIMA level and $15.43 for depot level [Ref. 10]) does not include all relevant overhead costs. All things considered, the actual cost of maintenance labor must be expected to be significantly higher than the cost computed by AIR.

5.2.3.3. Training Costs

According to MIL-STD-1390B, training cost is computed as

$$\sum_{s=1}^{n} NMT_s \times TCPM_s \times (1 + PAR_s) \times NDF$$

where:

n = the total number of sites.

NMT_s = the number of men trained, site s.

$TCPM_s$ = the training cost per man, site s.

PAR_s = the personnel attrition rate, site s.

NDF = the normal discount factor.

$NMT_s \times TCPM_s$ is the initial cost of training for site "S", and $NMT_s \times TCPM_s \times PAR_s$ is the average annual recurring cost of training for this site. As seen from the formula for total training cost, the initial cost is multiplied by NDF, which is a mistake. Unfortunately, this error

is found in AIR as well. The result is that the initial training cost is computed to be several times higher than the actual cost. For a life cycle period of fifteen years and a discount rate of three percent, the computed cost is twelve times higher than the actual value.

5.2.4. AIR Input Data

Two categories of input data are needed by this model:

a) Parameters and system data, which includes data defining the size of the problem (e.g., the number of sites, the number of systems per site, the different types of maintenance technicians), and data needed by the overall operation of the model, such as life cycle period, cost factors, repair cycle times, labor hourly rates, user specified LOR (level of repair) alternatives, and sensitivity analysis to be performed.

b) Site data, defining and describing the different maintenance levels and the support activities. Included are required days of stock, system data, and distant repair data.

Examples of input data are found in Appendix F.

5.2.5. AIR Output Reports

The results of a computer run are presented in six standard reports:

a) Total LSC, by alternative and indenture level.

b) Item summary report, costs by item and alternative.

c) LSC breakdown, by alternative and cost category.

d) Total inventory values, by item and alternative.

e) Per site inventory values.

f) Sensitivity analysis, by alternative and data set.

Six standard alternatives are always included in a run. Additionally, the user can specify up to forty other alternatives. The standard alternatives are:

a) All modules discarded at failure.

b) All WRA's repaired locally, all SRA's discarded.

c) All WRA's repaired locally, all SRA's optimized.

d) All WRA's repaired locally, all SRA's repaired at PIMA, and all SUB-SRA's optimized.

e) All WRA's repaired locally, all SRA's repaired at depot level, and SUB-SRA's optimized.

f) Least Cost Alternative, no predesignations of LOR codes are made.

Examples of AIR output reports are enclosed in Appendix F.

5.2.6. Limitations of AIR

Two of the main cost drivers of LSC, inventory and labor, are those least accurately computed by AIR. Concerning inventory costs, the model just follows the rules from MIL-STD-1390B(NAVY). But since the rules are not directly relatable to any measure of system effectiveness, AIR is considered by the writers to be inadequate as a tool for initial provisioning of spares and for prediction of inventory costs.

Labor costs are incorrectly computed, largely underestimating the actual costs.

AIR is unable to handle a system in which the same type of SRA is a part of two or more different WRA's. The computation of training costs is far from correct (Section 5.2.3.3.).

AIR is programmed in SIMSCRIPT. The lack of compilers at many facilities for this computer language may limit the utility of AIR.

5.3. THE OPUS-VII MODEL

OPUS-VII is a proprietary, computerized model developed by SYSTECON AB, Stockholm, Sweden. A description of OPUS-VII is enclosed as Appendix C, and a more complete description is found in the "OPUS-VII, Manual" [Ref. 18].

5.3.1. General Description of OPUS-VII

OPUS-VII is a unique tool for the following types of problems:

a) Cost-effectiveness evaluation of alternative maintenance and supply support concepts and alternative system configurations.

b) Initial procurement and allocation of spares within a support organization.

c) Reallocation of a given assortment of spares.

d) Replenishment procurement of spares.

e) Reallocation of a given assortment followed by replenishment procurement of spares.

f) Effectiveness evaluation of a given assortment of spares.

For each type of problem, one or more of the following measures of effectiveness (MOE) can be chosen:

a) System operational availability (A_o).

b) Probability of successful mission performance.

c) Risk of shortage when a spare is being demanded.

d) Mean waiting time for a spare (computed for each level of the maintenance organization).

The ability to combine the different types of problems by the different MOE's gives OPUS-VII a high degree of flexibility, which makes it useful for many problems concerning inventory levels.

5.3.2. Assumptions Used by OPUS-VII

The algorithms used in the program are based on the following assumptions:

-- The demands are Poisson distributed.

-- Mean values of turnaround times are known.

-- A failure of one item is statistically independent of those that occur for any other type of item.

-- Repair times are statistically independent.

-- No queues are assumed in the maintenance organization.

-- The system has been in operational use long enough that all transients have faded out.

5.3.3. OPUS-VII Input Data

The required input data can be divided into System data and Organizational data.

Recognizing that a specific module may be common to several types of systems, OPUS-VII can handle more than one system in a single run. Therefore, system data includes the number of system types, the number of each type of system, system MTBF, system breakdown into LRU's and SRU's, module MTBF, and item unit cost, to mention some of the more important.

The support organization must be built up in a hierarchical way as illustrated in Appendix C (Figure C-2). Examples of organizational input data are: reference to one or more stations supporting each site, time to repair every module at each station, and average time to get a spare from a superior support station given no shortage exists.

Examples of input data are found in Appendix F.

5.3.4. OPUS-VII Output

A variety of information is obtainable from OPUS-VII. A few examples are found in Appendix F.

In general, the output contains graphs showing the MOE as a function of investment, tables describing the number of each type of spare to be purchased and how these items are best allocated to the different stocks, tables showing how the initial investment costs are distributed with regard to the assortment and to the different levels of the organization, and the overall cost-effectiveness curve for the problem

5.3.5. Limitations of OPUS-VII

Most of the algorithms used in OPUS-VII have been checked, using a TI-59 (programmable handheld calculator) [Ref. 19]. No error was detected.

The assumption that demands are Poisson distributed is valid for electronic systems, but is less practicable for mechanical and some other types of equipment.

For some spares, it is normal in many organizations to batch a number of items before repair is undertaken. If so, OPUS-VII will overestimate the MOE.

5.3.6. Other Comments

OPUS-VII is written in FORTRAN IVH and can easily be implemented on any computer system having a FORTRAN capability.

5.4 THE SIMPLE MODEL

5.4.1. Introduction

The limitations of AIR make this model inadequate for parts of the analysis necessary to achieve the objectives of this thesis. In particular, the treatment of initial procurement of spares needed to be improved, a purpose for which OPUS-VII is available. Since the formulas for computation of all other elements of LSC are relatively simple, the Swedish approach [Ref. 20] was adopted, which is, for each procurement case, to develop and program a set of cost equations relevant for a specific system and a given support organization. A model, referred to as "SIMPLE," was developed based upon the discussion of cost elements in Section 3.3., through 3.4., the cost breakdown given in Figure 3-3, and the support organization used for the numerical analysis in Section 6.2. The intention of Chapter IV was to obtain a screening rule for repair/discard decisions in such a way that repair should <u>never</u> be undertaken if the unit cost of a module is below the critical value. As previously stated, the curve in Figure 4-2 favors the repair alternative. A more representative repair/discard model is included in SIMPLE.

As illustrated in Figure 3-3, each cost category is computed as the sum of several cost elements. Some of

these elements are calculated as functions of one or more of the other cost elements and several of them are used for comparison of repair and discard costs. Therefore, the cost elements must be computed in a specified order. An interactive computer program for control of LSC computations has been designed by Lt. Colonel L. Pålsson, Air Materiel Department, Swedish Air Force, Stockholm. This program is used for control of cost computations in SIMPLE.

5.4.2. Cost Computations in SIMPLE

The LSC breakdown illustrated in Figure 3-3 is used almost unchanged (the differences are described in Appendix E). Cost equations are based upon Chapter III and the formulas for change in LSC if an item is discarded at failure are based on Chapter IV.

Formulas used for computation of each cost element and a listing of variable names are found in Appendix E. Input and output data are included in Appendix F.

It must be emphasized that the cost equations found in Appendix E are valid only for the basic organization and the level of repair policy described in Section 6.2. When either of those is changed (numerical analysis, Chapter VI), the cost equations affected must be changed as well.

5.4.2.1. Manpower Costs

Compared to AIR, SIMPLE includes the labor cost of preventive maintenance. Furthermore, the "average manhours per corrective maintenance action" includes the total number of manhours associated with the repair action

(Section 3.3.1.). Accordingly, the cost of maintenance manpower is significantly higher in SIMPLE than it is in AIR.

5.4.2.2. Test and Support Equipment Costs

Evaluating the LSC of a system already designed, it is assumed that the requirement for peculiar test and support equipment (TSE) is determined by the system design and that the procurement cost per site (for a given LOR policy) is an input to the model. The investment in common TSE is determined by the utilization of what is in inventory already and is, therefore, considered an input as well. The procedure used by AIR for estimation of the annual support cost of TSE is adopted.

5.4.2.3. Inventory Costs in SIMPLE

The initial procurement cost of spares is computed by OPUS-VII and used as input to SIMPLE. For replenishment of spares, entering and holding costs, and the cost of consumables, the cost equations are similar to those used by AIR.

5.4.2.4. Training Costs

Compared to AIR, the main difference is that SIMPLE includes the cost of training equipment and materiel, and the correct equation is used.

5.4.2.5. Transportation Cost

The computation of transportation cost in SIMPLE is based upon the following three variables: (1) the transportation cost per mile, (2) the annual number of items shipped from each site to its supporting site, and (3) the

average distance between a level of the organization and the maintenance level supporting it. Finally, the transportation cost is a function of the level of repair policy.

5.4.2.6. Other Elements of LSC

In SIMPLE, "Other Costs" include the cost of space, documentation, and other costs not included in any of the other categories.

The cost of space is determined by factors as the size of the system, the number of systems procured, the size and the amount of test and support equipment, and facilities available already. No general equation can cover this cost element. The initial cost of space is an input to SIMPLE. The annual cost of using and maintaining the facilities is computed as a fraction of the investment cost.

The cost of documentation is computed as the sum of the costs for all sites. An annual recurring cost of maintaining the documentation is computed as a fraction of the investment cost.

Other elements of this cost category are input to SIMPLE.

5.4.3. Repair vs. Discard Cost in SIMPLE

SIMPLE computes for each LRU and SRU the change in LSC if the module is discarded instead of repaired at failure. A negative value indicates that a saving can be obtained if a discard policy is chosen. Because non-economic factors may enter a repair/discard decision, this value is not subtracted from the LSC computed, but must be so, if the discard alternative is chosen.

The equations used for computation of delta costs are based on the general formulas (not the numerical example) found in Chapter IV.

5.4.4. Input and Output Data, SIMPLE

The input data is almost the same as for AIR. The main differences are that the initial investment in spares is an input from OPUS-VII and that SIMPLE requires other data for calculation of transportation costs.

The important output data is

-- LSC (life support costs).

-- Initial investment.

-- Recurring costs, discounted for the life cycle.

-- The costs for each of the cost categories used in this thesis.

-- The value of each cost element, Figure 3-3.

-- For each module, the change in LSC if a discard policy is chosen.

5.4.5. Limitations of SIMPLE

SIMPLE is a simplified model. Compared to AIR the number of program statements has been reduced by a factor of approximately one hundred. The cost of doing so is that a level of repair policy and a suggestion to initial procurement of spares are to be obtained from external sources. The estimates of LSC and its elements are of the same or a better accuracy than those obtained by AIR.

Initial cost of space, documentation, and common test and support are input data.

A natural next step would be to include a "Lowest LSC" capability in SIMPLE. This could be done based on the decision tree (Figure 3-4). With OPUS-VII available, the effort to program a model for initial procurement would not be worthwhile.

In a real situation more information about the support organization, the equipment considered, facilities needed, and other factors affecting LSC would be available and some of the cost equations used in SIMPLE could be improved. But the purpose of an LSC model should be remembered and the model not made more complex than necessary to obtain a reasonably accurate prediction of the difference in LSC for alternative systems.

5.5. USE OF THE MODELS

The models described above are used for the numerical example in Chapter VI. The interactions between the models are illustrated in Figure 5-1.

As seen from the figure, OPUS-VII is used for more than one purpose. The initial investment in spares is computed and used as an input to SIMPLE. The operational availability which can be expected for the allocation of spares as computed by AIR is calculated by OPUS-VII.

To check SIMPLE and AIR, the LSC categories computed by the two models are compared.

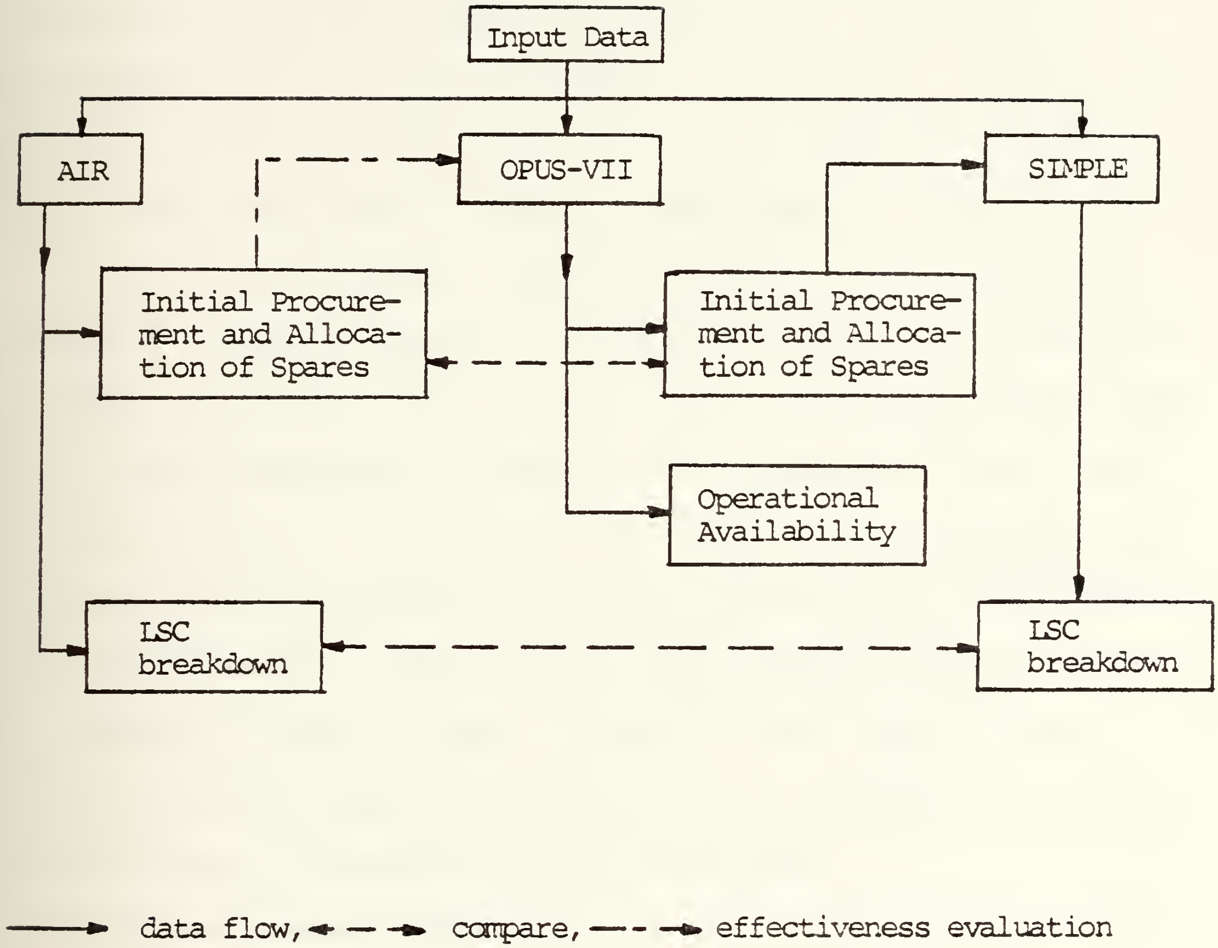

Figure 5-1. Use of the Models

VI. NUMERICAL EXAMPLE

6.1. INTRODUCTION

The intention of this chapter is to demonstrate with a numerical example the impact of system and organizational characteristics and other selected variables on initial procurement of spares and other significant elements of LSC. The models described in Chapter V are used for this purpose.

The amount of input data required by the models described in Chapter V makes it evident that LSC is a function of many variables. Fortunately, for a given system procured for a given organization, many of the variables can be considered constants, that is, either they will not affect the choice between alternative systems, or they will not influence LSC significantly. Eliminating such variables and others, the impact of which on LSC is readily seen from the cost equations, the number of selected input variables explored in this chapter is reduced to the following:

a) System characteristics:
   - -- MTBF (Section 6.7.1)
   - -- MTTR (Section 6.7.2)

b) Organizational Structure and different maintenance policies:
   - -- Number of intermediate level sites (Section 6.7.3.1)
   - -- Eliminating depot level (Section 6.7.3.2)
   - -- Eliminating intermediate level (Section 6.7.3.3)

-- Transportation time, organizational to intermediate level (Section 6.7.3.1)

-- Turn-around time depot level (Section 6.7.3.3).

c) Other input variables:

-- Number of systems procured (Section 6.7.5.1)

-- Discount rate (Section 6.7.5.2)

-- Life cycle period (Section 6.7.5.3)

The impact of the factors listed above on repair/discard decisions is described and the breakeven curve (unit cost and number of failures) determined (Section 6.7.6). Furthermore, it is demonstrated that some variables not included in the analysis (labor rate and condemnation rate) may affect LSC significantly (Section 6.7.5.4).

The initial procurement of spares is not treated analytically either in Israel or in Denmark. Therefore, special treatment is given to this issue (Section 6.6).

6.2. THE SUPPORT ORGANIZATION

The support organization used for the numerical example is chosen as it reflects a support policy often used in Israel and Denmark. It consists of three maintenance levels:

a) Organization Level (OL)

b) Intermediate Level (IL)

c) Depot Level (DL).

24 identical systems are assumed deployed in two separate areas (16 and 8 in each area). Two intermediate level sites support the organizational level. One depot level site supports

both intermediate level sites. The support organization is built-up in a hierarchical way, and only vertical relationships are allowed between the maintenance sites. Each maintenance site may have its own stock of spares.

The support organization is presented in Figure 6-1. DEP is the depot level site, IN1 and IN2 are intermediate level sites, and MN1 and MN2 are organizational level support sites.

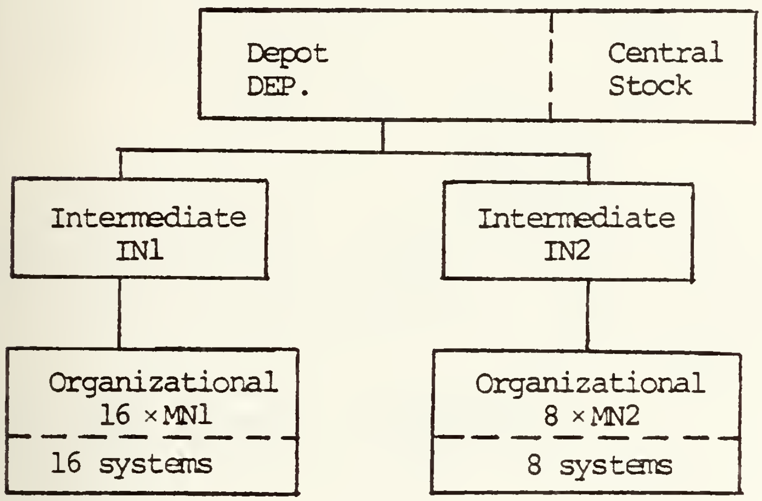

Figure 6-1. The Support Organization

6.2.1. Maintenance Policy

When a failure occurs in a system, the failed LRU is isolated and replaced, and after a verification action, the system is restored to an operational condition. The failed LRU is sent to intermediate level where it is restored by replacement of the failed SRU, and verified. The failed SRU is sent from IL to DL, where it is repaired. Failed units which are defined as discardable are replaced and discarded.

6.2.2. Stockage Policy

LRU's may be stocked at DL as replacement for failed LRU's. Both LRU's and SRU's are allowed to be stocked at IL and DL.

6.3. SYSTEM BREAKDOWN

A hypothetical, electronic system is used as an example for the analysis. The system includes six different LRU's and eleven different SRU's. The system breakdown is presented in Figure 6-2.

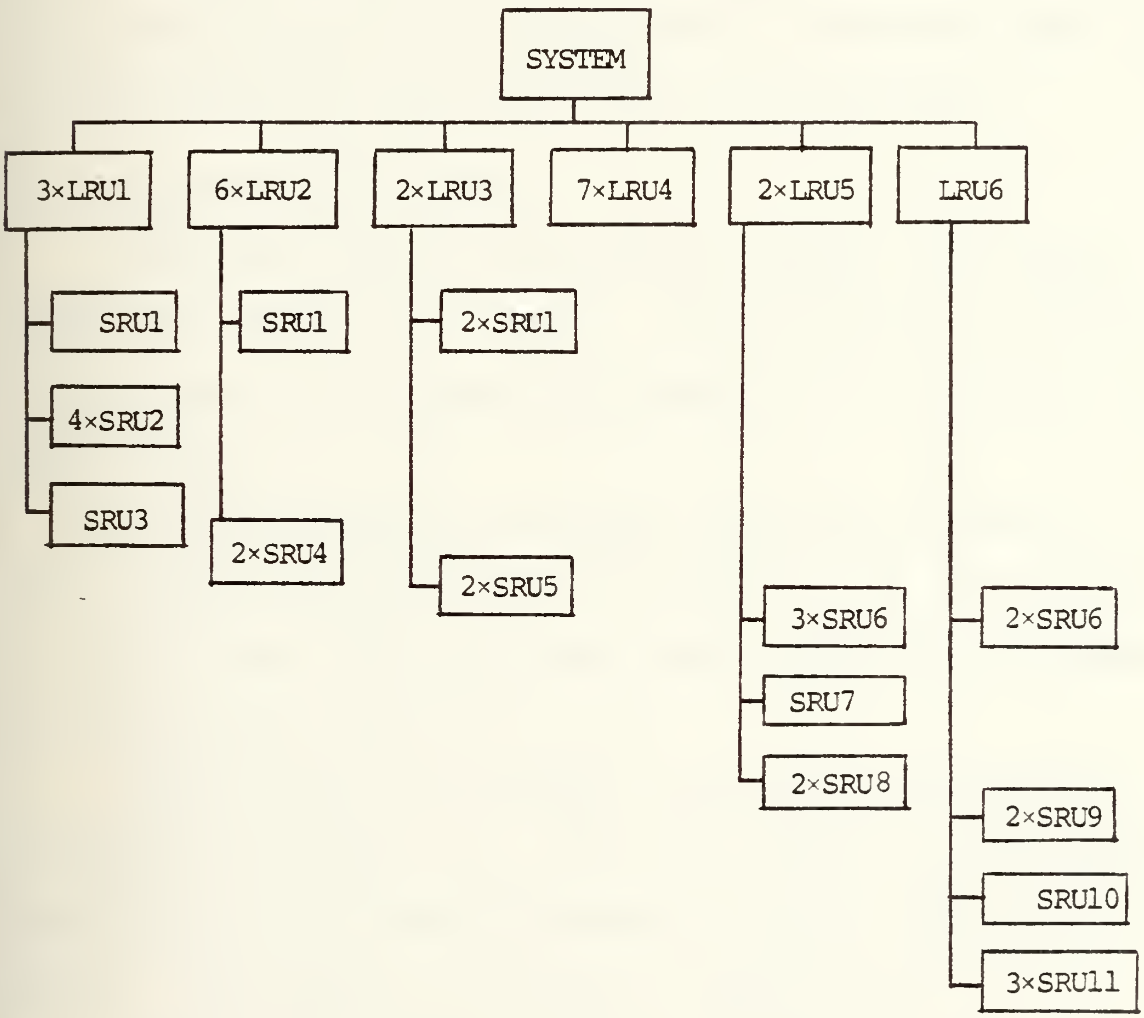

Figure 6-2. System Breakdown

6.4. INPUT DATA

Although the support organization and the system are hypothetical, the data used are considered representative for a system operated and supported in an actual military organization. The input data is included in Appendix F. This identifies the model(s) for which each variable is used as an input. Where two of the models require different input variables to compute an output, attempts have been made not to favor any one of the models. For example, AIR and OPUS-VII do not use the same elements of the turn-around time for a failed item, but the values of the input data used assure that the total turnaround time is the same for both models.

6.5. COMPARISON OF OUTPUT

The first step of the analysis compares the output from AIR, OPUS-VII, and SIMPLE. As illustrated by Figure 6-3, the "common" set of input data (Appendix F) is used for all three models.

To compare the LSC breakdown from AIR and SIMPLE, a user specified alternative, in accordance with Section 6.2.1, is used in AIR. The AIR "Least Cost Alternative" is discussed and evaluated in Section 6.6.1.1.

The LSC and its breakdown, as obtained from AIR, is illustrated in Table 6-1. Each cost category can be further broken down with a share allocated to LRU's, SRU's, and sub-SRU's. (An example is included in Appendix F.)

Some of the cost categories in Table 6-1 require further explanation. INVENTORY is the initial procurement cost of

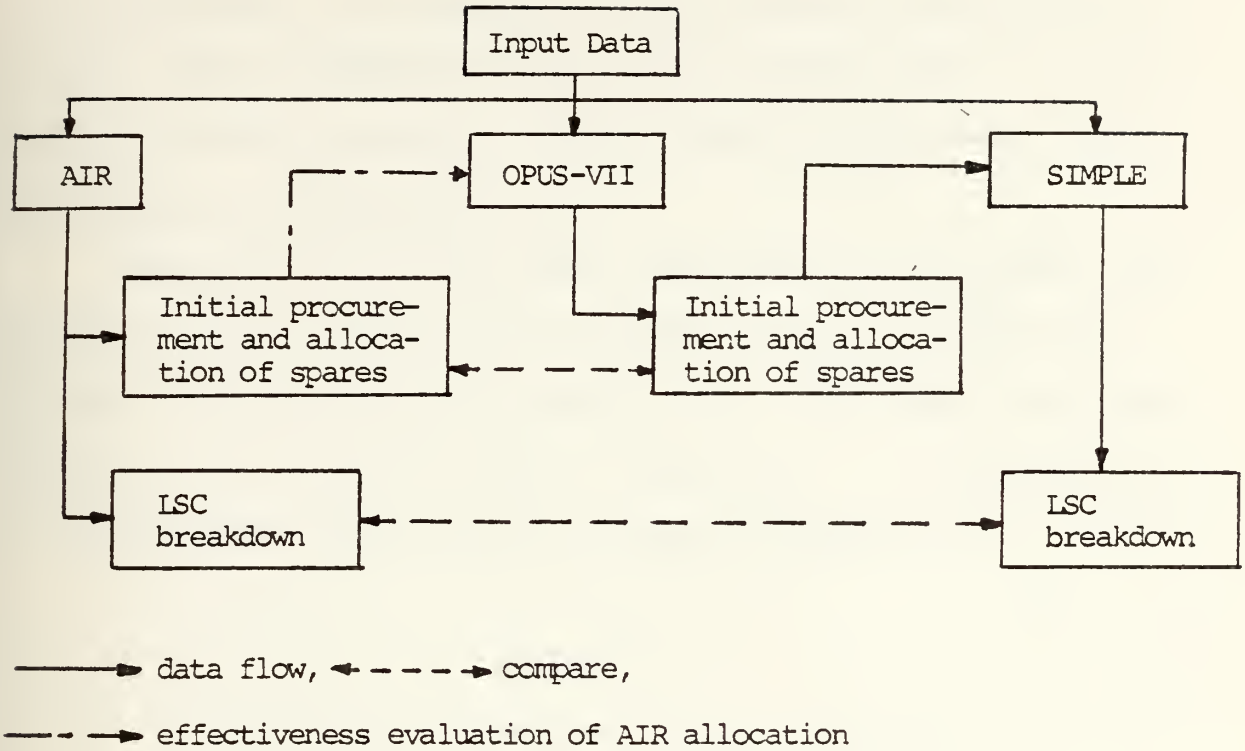

Figure 6-3. Comparison of Model Output

Table 6-1

AIR Cost Breakdown

COST CATEGORY	TOTAL $	%
SUPPORT EQUIPMENT (SE)	154050	3.86
SUPPORT OF SE	198860	4.98
INVENTORY (INV.)	901930	22.59
INV. ADMINISTRATION	293413	7.35
SE SPACE	40230	1.01
INV. STORAGE	5020	.13
REPAIR SPACE	0	0.
LABOR	697320	17.47
MATERIAL	348700	8.73
TRANSPORTATION	306865	7.69
REPAIR SCRAP	547165	13.71
TRAINING	495905	12.42
DOCUMENTATION	2730	.07
TOTAL	3992188	100.00

LRU's and SRU;s. INV.ADMIN. is the inventory entering and holding costs. MATERIAL is the cost of piece parts used for repair of LRU's and SRU's. REPAIR SCRAP is the cost of replenishment procurements.

Compared to AIR, the cost breakdown in the output from SIMPLE is more detailed and includes the cost of each cost element (as illustrated in Figure 3-3). The major cost categories of the output are shown in Table 6-2. A complete printout of the basic input data is found in Appendix F.

Table 6-2

SIMPLE Cost Breakdown (basic version)

$		COST CATEGORY
4666829	LSC :	LIFE SUPPORT COSTS, DISCOUNTED, NY YEARS
2034667	TMANPW:	LSC,MANPOWER
356156	TTSE :	LSC,TEST AND SUPPORT EQUIPMENT (T&SE)
1694450	TINVEN:	LSC,INVENTORY
193719	TTRAIN:	LSC,TRAINING
294207	TTRANS:	LSC,TRANSPORTATION
93630	TOTHER:	LSC,OTHER ELEMENTS
804315	A :	INITIAL INVESTMENT,SUPPORT ACTIVITIES
323551	R :	ANNUAL RECURRING COSTS
3862514	RN :	ANNUAL RECURRING COSTS,NY YEARS

To facilitate comparison between the cost computation in the two models, costs are allocated to the six major categories described in Section 3.3, as illustrated in Table 6-3.

Table 6-3

LSC, AIR and SIMPLE ($ 1,000)

COST CATEGORY	AIR	SIMPLE
LSC	3,992	4,670
Maintenance manpower	697	2,034
Test and support equipment	353	356
Inventory	2,091	1,697
Training	496	194
Transportation	307	294
Other costs	48	94

The difference in maintenance manpower costs is caused by the fact that AIR computes the cost of active repair time only. SIMPLE includes the average total time per repair action plus a cost for preventive maintenance. One hour per day per system spent on periodic checks and adjustments or other preventive actions performed by maintenance personnel accounts for M$ 1.05 during the life cycle. The cost of active repair time computed by the two models is the same.

A significant difference in inventory costs exists ($394,000). The main reason for this is that the required initial investment in spares (computed by OPUS-VII) is $374,000 lower in SIMPLE. This issue is discussed in Section 6.6.1.1. The replenishment procurement and inventory administration costs are almost the same for both models.

The difference in training costs is due to an incorrect formula used in AIR, which is discussed in Section 5.2.3.3.

The 100 percent difference in "Other Costs" is the result of an annual recurring cost of maintaining documentation, data, and new maintenance space included in SIMPLE but not in AIR.

6.6. INITIAL PROCUREMENT OF SPARES

In this numerical example, spares are procured in such quantities that allow achievement of an operational availability (A_o) of approximately 97.0%, at the time the new systems are introduced into the operational environment. Usually, more spares are added to this basic inventory, initially resulting in a higher value of the achieved A_o. (This assures that A_o will remain above the minimum value until replenishment is received.) In this case A_o can be viewed as the minimum requirement. To maintain this standard, a replenishment procurement is performed (an annual basis is assumed for replenishment procurements).

MTBF and actual repair time at the organizational level (including transportation time) initially have the values of 291.2 hours for system MTBF and 2.3 hours for actual repair time at the organizational level. The actual repair time includes:

-- 1.3 hours for active repair time, and

-- 1.0 hours for transportation (round-trip)

The quantities of spares to be procured initially depend on

the period of time to be covered by them (from two years up to the whole life cycle period), budgetary constraints, and the measure of effectiveness (MOE) used to determine the required level of effectiveness with this inventory. At the time when the initial procurement is ordered, the maintenance organization and the repair policy should already have been defined and can be considered as given.

Holding A_o at a fixed level, it is possible to determine the impact of each of the main variables on the initial procurement cost. The impact of the following variables is explored below:

a) mean time between failures (MTBF);

b) active repair time at the organizational level (MTTR);

c) turnaround time at the depot level;

d) Organizational structure.

Other variables are considered as fixed at the time the initial procurement of spares evaluation is performed or as having an insignificant impact.

6.6.1. Impact of Mean Time Between Failures on Initial Procurement of Spares

The uncertainty with regard to MTBF to be achieved in the operational environment (Section 2.2.1) is a key factor in any decision concerning the investment in initial procurement of spares (IIPS). A priori, to consider the consequences of an MTBF to be obtained during the use of a new equipment different from the one predicted requires an adequate model, advanced enough to evaluate any possible variation.

If $MTBF_D$ is the expected value and $MTBF_O$ is the value of MTBF obtained in the operational environment, field data indicates [Ref. 8] that $MTBF_O$ will normally be within the following limits.

$$2MTBF_D \geq MTBF_O \geq MTBF_D/6$$

The cases which are explored in this thesis are:

a) $MTBF_O = MTBF_D$, and

b) $MTBF_O = MTBF_D/4$

The problem one faces, then, is whether to rely upon the MTBF data provided by the manufacturer ($MTBF_O = MTBF_D$) or to assume that the actual MTBF in the operational environment will be four times worse ($MTBF_O = MTBF_D/4$). As demonstrated below, this decision is very significant to the cost of initial procurement of spares. After the systems are introduced into the operational environment, the two possibilities described above may develop into four different scenarios:

a) $[MTBF_O = MTBF_D / MTBF_O = MTBF_D]$

b) $[MTBF_O = MTBF_D/4 / MTBF_O = MTBF_D/4]$

c) $[MTBF_O = MTBF_D / MTBF_O = MTNF_D/4]$

d) $[MTBF_O = MTBF_D/4 / MTBF_O = MTBF_D]$

where $[X = Y / X = Z]$ should be read as: "initial procurement of spares was performed assuming X = Z, when actually X = Z (or X = Y) was obtained." Each of these four scenarios is

discussed below, and illustrated in Figures 6-4 and 6-5. These figures present the waiting time (WT) and A_o as functions of investment in initial procurement of spares (IIPS). Scenarios a,b,c,d correspond to curves 1,2,3, and 4, respectively. All curves are approximated by continuous functions, although their precise representation is step functions. All scenarios are analyzed for an IIPS of $528,000.

6.6.1.1. First Scenario, $MTBF_o = MTBF_D$/$MTBF_o = MTBF_D$

For this case, an investment of $528,000 suggested by OPUS-VII enables the achievement of an A_o of 97.5%. Inventory data and MOE values are presented in Table 6-4. The abbreviations used in this table are adopted from OPUS-VII. Some of them require additional explanation:

DEP = depot level site;

IN1/IN2 = intermediate level site number 1 and 2, respectively;

MN1/MN2 = the maintenance level directly supporting the system level (part of organizational level).

Availability:

System 1: Denomination of the system

Total : OPUS-VII can handle more than one system in a single run. "Total" is a weighted average of A_o if more than one system is included in the analysis;

OR1/OR2: A_o for systems supported by intermediate level site 1 and 2, respectively.

Investment:

Perc ESS: Percent of total investment used for depot level

Perc First Level: Percent of total investment used for organizational level.

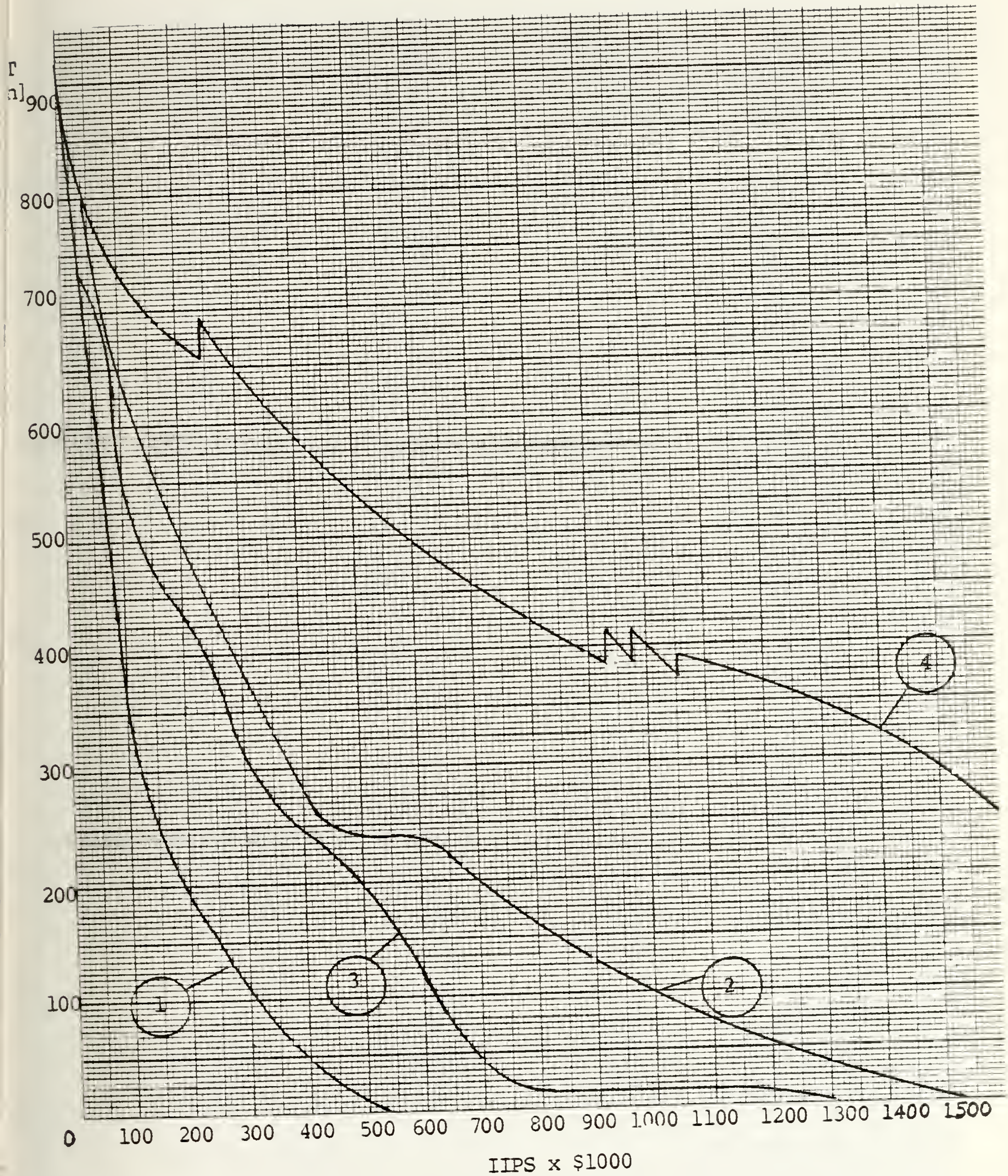

Figure 6-4. WT as a function of IIPS

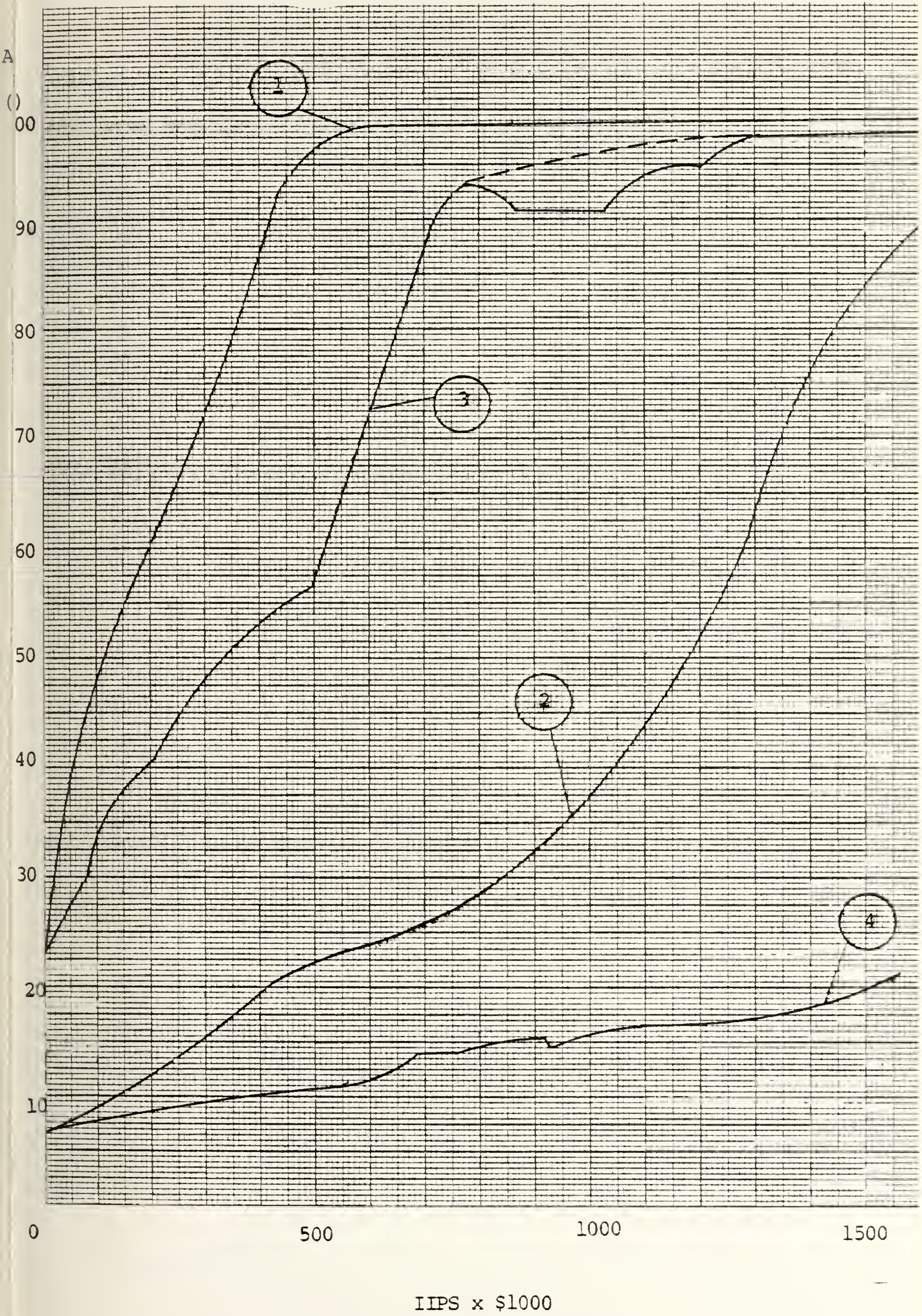

Figure 6-5. A_o as a Function of IIPS

Table 6-4

Inventory Data and MOE Values of the First Scenario (OPUS-VII)

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	16× MN1	8× MN2
LRU 1	4	12300.0	0	2	2	0	0
LRU 2	8	37640.0	0	5	3	0	0
LRU 3	3	12480.0	0	2	1	0	0
LRU 4	5	15200.0	0	3	2	0	0
LRU 5	5	53350.0	0	3	2	0	0
LRU 6	24	278520.0	15	6	3	0	0
SRU 1	15	15300.0	10	3	2	0	0
SRU 2	7	2275.0	4	2	1	0	0
SRU 3	4	1940.0	2	1	1	0	0
SRU 4	24	42480.0	16	5	3	0	0
SRU 5	4	3840.0	2	1	1	0	0
SRU 6	13	27365.0	7	4	2	0	0
SRU 7	3	3015.0	1	1	1	0	0
SRU 8	6	9450.0	3	2	1	0	0
SRU 9	4	2960.0	2	1	1	0	0
SRU10	2	1780.0	1	1	0	0	0
SRU11	6	8070.0	3	2	1	0	0

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION: OR1	OR2
SYSTEM 1	0.97465	0.97896	0.96605
TOTAL :	0.97465		

INVESTMENT

TOT INVESTM.	=	527965.0
PERC E S S	=	46.1
PERC FIRST LEVEL	=	0.0
PERC LRU	=	77.6
PERC SRU	=	22.4

MEASURE OF EFFECTIVENESS

AVAILABILITY (A_o)	=	0.97465
N O R S	=	0.60829
WAITING TIME	=	5.28426
RISK OF SHORTAGE	=	1.000000
RSK OF SHRTGE(1ST LVL)	=	1.000000

Measure of Effectiveness:

NORS: The expected number of non-available systems

Risk of Shortage: The probability that a given demand (at any site) cannot be satisfied within a given time (T) due to shortage in stock.

RSK SHRTGE (1st LVL): The probability of shortage, given a demand, at organizational level.

(Table 6-4) differs significantly from that suggested by AIR (Table 6-5). The main reason for this is the difference in MOE's used by the models. While OPUS-VII bases its procurement of spares on one or more of several well-known MOE's. AIR uses as its MOE a 95% of requisitions fulfillment which to the authors appears to be less adequate. Comparison of the two suggestions reveals:

Table 6-5

Initial Procurement of Spares Suggested by AIR

MODULE	TOTAL*	24× OPER. SITE	DEPOT/CENTRAL STOCK
LRU 1	1		1
LRU 2	50	2	2
LRU 3	1		1
LRU 4	25	1	1
LRU 5	25	1	1
LRU 6	25	1	1
TOTAL COST LRU's	875,360 (97%)		
SRU 1	4		4
SRU 2	1		1
SRU 3	1		1
SRU 4	5		5
SRU 5	1		1
SRU 6	3		3
SRU 7	1		1
SRU 8	1		1
SRU 9	1		1
SRU10	1		1
SRU11	1		1
TOTAL COST SRU's	26,570 (3%)		
TOTAL COST	901,930 (100%)		

*no spare parts are suggested to be stocked at the intermediate level

a) AIR invests $875,360 in LRU's procurement, while OPUS-VII invests $409,700, only.

b) OPUS-VII invests $118,265 in SRU's procurement, while AIR invests $26,570 only.

c) Totally, AIR invests $373,965 more than OPUS-VII (+70.8%) in initial procurement of spares.

d) AIR spends 97% of the investment on LRU's, vs. 77.6% spent by OPUS-VII (the rest is spent on SRU's).

e) AIR stocks 94.5% of LRU's at operational sites, and the rest at the central stock. OPUS-VII stocks 69.4% of LRU's at the intermediate level, and the rest at the central stock.

f) AIR stocks all SRU's at the depot level, while OPUS-VII stocks 42% of SRU's at the intermediate level, and the rest at the depot level.

A_o is not calculated by AIR. To evaluate A_o, the initial procurement of spares suggested by AIR was used as input to an effectiveness evaluation version of OPUS-VII. The results are presented in Table 6-6. A_o obtained by the initial procurement of spares suggested by AIR is only 56%, which is too low for military organizations. A part of the procured LRU's turns out to be superfluous, as no improvement of A_o is obtained due to their procurement. (Elimination of LRU's 1 to 5 from the central stock saves more than $30,000, and only slightly lowers the obtained A_o.) Recalling that by using OPUS-VII, an A_o of 97.5% is obtained with $373,965 less invested indicates the advantages of the MOE used in OPUS-VII.

Table 6-6

Inventory Data and A_o for Initial Procurement of Spares Suggested by AIR

DENOM	TOTAL	DEP	IN1	IN2	16× MN1	8× MN2
LRU 1	0	0	0	0	0	0
LRU 2	48	0	0	0	2	2
LRU 3	0	0	0	0	0	0
LRU 4	24	0	0	0	1	1
LRU 5	24	0	0	0	1	1
LRU 6	25	1	0	0	1	1
SRU 1	4	4	0	0	0	0
SRU 2	1	1	0	0	0	0
SRU 3	1	1	0	0	0	0
SRU 4	5	5	0	0	0	0
SRU 5	1	1	0	0	0	0
SRU 6	3	3	0	0	0	0
SRU 7	1	1	0	0	0	0
SRU 8	1	1	0	0	0	0
SRU 9	1	1	0	0	0	0
SRU10	1	1	0	0	0	0
SRU11	1	1	0	0	0	0

TOT INVESTM. = 871575 AVAILABILITY = 0.559

The results obtained by AIR can be improved by reallocating the initially procured inventory. Using a reallocation version of OPUS-VII, an A_o of 76.6% is obtained. Table 6-7 presents the reallocated assortment of spares. The improvement is achieved by moving LRU's from the organizational to the intermediate and to the depot level, where the LRU's are more effective. Once again, OPUS-VII is more cost-effective than AIR. Therefore, the analysis concerning initial procurement of spares is mainly based upon OPUS-VII. To verify the "least cost alternative" which AIR suggests, the spares allocation and the level of repair (maintenance policy) suggested by AIR were used as input data to OPUS-VII.

Table 6-7

Reallocated Inventory Data, and A_o of Initial Procurement of Spares Suggested by AIR

DENOM	TOTAL	DEP	IN1	IN2	16× MN1	8× MN2
LRU 1	1	0	1	0	0	0
LRU 2	50	0	26	16	0	1
LRU 3	1	0	1	0	0	0
LRU 4	16	0	5	3	0	1
LRU 5	25	0	15	10	0	0
LRU 6	25	13	8	4	0	0
SRU 1	4	4	0	0	0	0
SRU 2	1	1	0	0	0	0
SRU 3	1	1	0	0	0	0
SRU 4	5	5	0	0	0	0
SRU 5	1	1	0	0	0	0
SRU 6	3	3	0	0	0	0
SRU 7	1	1	0	0	0	0
SRU 8	1	1	0	0	0	0
SRU 9	1	1	0	0	0	0
SRU10	1	1	0	0	0	0
SRU11	1	1	0	0	0	0

TOT INVESTM. = 874570 AVAILABILITY = 0.766

Applying this maintenance policy, an A_o of 97.5% is obtained for an initial investment in spares of \$612,000 (vs. \$528,000 required when all LRU's are repaired at the intermediate level, and all SRU's are repaired at the depot level).

6.6.1.2. Second Scenario, $MTBF_o = MTBF_D/4$
$MTBF_o = MTBF_D/4$

For this case an investment of \$520,500 (corresponding to an A_o of 97.5% for the first scenario) results in an A_o of 23.0% (OPUS-VII). Inventory data and A_o are presented in Table 6-8. An A_o of 23.0% is unacceptable for military organizations.

Table 6-8

Inventory Data and A_o of the Second Secenario (OPUS-VII)

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	4	0	3	1
LRU 2	12	0	8	4
LRU 3	3	0	2	1
LRU 4	6	0	4	2
LRU 5	1	0	1	0
LRU 6	3	0	3	0
SRU 1	49	38	7	4
SRU 2	18	13	3	2
SRU 3	8	5	2	1
SRU 4	83	64	12	7
SRU 5	10	7	2	1
SRU 6	45	30	10	5
SRU 7	6	3	2	1
SRU 8	17	11	4	2
SRU 9	9	6	2	1
SRU10	4	2	1	1
SRU11	16	11	3	2

TOT INVESTM. = 520455 AVAILABILITY = 0.230

A priori assuming a situation where $MTBF_O = MTBF_D/4$, an investment of approximately \$2,500,000 is required to obtain an A_o of 96.9% (Table 6-9). Such an investment in initial procurement of spares (70% of acquisition cost) seems unrealistic. For this case, AIR suggests an investment for initial procurement of spares of \$3,343,000 (\$3,255,000 in LRU's, and \$88,000 in SRU's). This suggestion overruns the one suggested by OPUS-VII by \$843,000 (33.7%), but the value of A_o obtained is only 39.3%. LRU's 1 to 5 procured for the central stock are found by OPUS-VII to be redundant, which results in an unnecessary expenditures of

Table 6-9

Replenishment Inventory Data ("Target Inventory") and A_o of the Second Scenario

DENOM	TOTAL	DEP	IN1	IN2	16× MN1	8× MN2
LRU 1	32	0	5	3	1	1
LRU 2	43	0	12	7	1	1
LRU 3	31	0	4	3	1	1
LRU 4	34	0	6	4	1	1
LRU 5	34	0	6	4	1	1
LRU 6	105	62	12	7	1	1
SRU 1	49	38	7	4	0	0
SRU 2	18	13	3	2	0	0
SRU 3	8	5	2	1	0	0
SRU 4	84	64	13	7	0	0
SRU 5	10	7	2	1	0	0
SRU 6	47	30	11	6	0	0
SRU 7	6	3	2	1	0	0
SRU 8	17	11	4	2	0	0
SRU 9	9	6	2	1	0	0
SRU10	4	2	1	1	0	0
SRU11	17	11	4	2	0	0

TOT INVESTM. = 2497155 AVAILABILITY = 0.969

\$104,000 by AIR. Reallocation of the inventory suggested by AIR improves A_o to 52.5%.

6.6.1.3. Third Scenario, $MTBF_o = MTBF_D / MTBF_o = MTBF_D/4$

For this case, utilizing \$490,000 results in an A_o of 59.5% (OPUS-VII). It can be noticed that some of the quantity of SRU's procured under the assumption of $MTBF_o = MTBF_D/4$ do not contribute to availability when it turns out that $MTBF_o = MTBF_D$. Hence, more than \$30,000 is wasted on procurement of SRU's that do not improve A_o (and WT). For this case, inventory data and A_o are presented in Table 6-10. Reallocation of this inventory does not improve

Table 6-10

Inventory Data and A_o of the Third Scenario (OPUS-VII)

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	4	0	3	1
LRU 2	12	0	8	4
LRU 3	3	0	2	1
LRU 4	6	0	4	2
LRU 5	1	0	1	0
LRU 6	3	0	3	0
SRU 1	45	34	7	4
SRU 2	18	13	3	2
SRU 3	8	5	2	1
SRU 4	68	49	12	7
SRU 5	10	7	2	1
SRU 6	45	30	10	5
SRU 7	6	3	2	1
SRU 8	17	11	4	2
SRU 9	9	6	2	1
SRU10	4	2	1	1
SRU11	16	11	3	2

TOT INVESTM. = 489825 AVAILABILITY = 0.594

the obtained A_o. In order to reach an acceptable A_o, an additional investment of $234,000 is required, increasing A_o to 97.4% (Table 6-11).

Investigation of curve #3 in Figure 6-5 reveals an interesting phenomenon. In the investment interval of $770,000-$1,020,000, A_o is lower for higher than for lower investments. This implies that within this interval, "the higher the investment, the lower the effectiveness." The explanation of this phenomenon depends on the fact that curve #3 is a result of an optimization process performed for the case [$MTBF_o = MTBF_D/4$/$MTBF_o = MTBF_D/4$]. Within this investment interval, A_o illustrated by curve #2 (Figure 6-5)

Table 6-11

Replenishment Inventory Data ("Target Inventory") and A_O of the Third Scenario (OPUS-VII)

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	4	0	3	1
LRU 2	12	0	8	4
LRU 3	3	0	2	1
LRU 4	6	0	4	2
LRU 5	3	0	2	1
LRU 6	24	16	5	3
SRU 1	45	34	7	4
SRU 2	18	13	3	2
SRU 3	8	5	2	1
SRU 4	68	49	12	7
SRU 5	10	7	2	1
SRU 6	45	30	10	5
SRU 7	6	3	2	1
SRU 8	17	11	4	2
SRU 9	9	6	2	1
SRU10	4	2	1	1
SRU11	16	11	3	2

TOT INVESTM. = 754870 AVAILABILITY = 0.974

improves continuously as the investment increases, mainly due to procurement of additional LRU's. But as MTBF turns out to be four times better, these additional LRU's are revealed to be unnecessary. Therefore, A_O (and WT) remain at a fixed level, although more resources are used for procurement of additional LRU's. An improvement can be achieved by inventory reallocation. For example, after reallocation of the inventory presented in Table 6-12 (a specific point on curve #3, Figure 6-5, Investment = $826,745), A_O rises from 91.5% to 95.5% ($88,000 can be "saved" by this action). The reallocated assortment of spares for this point is presented in Table 6-13. Applying the reallocation procedure to all points within the

Table 6-12

Inventory Data and A_o of a Point on Graph #3 within a Fixed A_o (and WT) Interval

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	3	0	2	1
LRU 2	12	0	8	4
LRU 3	3	0	2	1
LRU 4	6	0	4	2
LRU 5	1	0	1	0
LRU 6	32	32	0	0
SRU 1	45	34	7	4
SRU 2	18	13	3	2
SRU 3	8	5	2	1
SRU 4	68	49	12	7
SRU 5	10	7	2	1
SRU 6	46	30	10	6
SRU 7	6	3	2	1
SRU 8	17	11	4	2
SRU 9	9	6	2	1
SRU10	4	2	1	1
SRU11	17	11	4	2

TOT INVESTM. = 826745 AVAILABILITY = 0.915

Table 6-13

Inventory Data and A_o of Reallocated Table 6-9 (OPUS-VII)

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	3	0	2	1
LRU 2	12	0	7	5
LRU 3	3	0	2	1
LRU 4	6	0	4	2
LRU 5	1	0	1	0
LRU 6	31	18	8	5
SRU 1	33	11	12	10
SRU 2	18	3	8	7
SRU 3	8	1	4	3
SRU 4	46	19	15	12
SRU 5	10	2	4	4
SRU 6	34	11	13	10
SRU 7	6	1	3	2
SRU 8	17	4	7	6
SRU 9	9	1	5	3
SRU10	4	1	2	1
SRU11	17	4	7	6

TOT INVESTM. = 738700 AVAILABILITY = 0.955

investment interval of \$770,000-\$1,020,000 improves curve #3 significantly. The improvement is represented by the dashed curve on top of curve #3 (Figure 6-5).

6.6.1.4. Fourth Scenario, $MTBF_O = MTBF_D/4$

$MTBF_O = MTBF_D$

For this case using OPUS-VII, an investment of \$528,000 results in an A_o of only 11.5% (Table 6-14). This situation is the most intolerable of all the four scenarios. To obtain an acceptable value of A_o, an additional investment of \$2,000,000 is required (the "target inventory" is described in Table 6-9).

Table 6-14

Inventory Data and A_o of the Fourth Scenario (OPUS-VII)

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	4	0	2	2
LRU 2	8	0	5	3
LRU 3	3	0	2	1
LRU 4	5	0	3	2
LRU 5	5	0	3	2
LRU 6	24	15	6	3
SRU 1	15	10	3	2
SRU 2	7	4	2	1
SRU 3	4	2	1	1
SRU 4	24	16	5	3
SRU 5	4	2	1	1
SRU 6	13	7	4	2
SRU 7	3	1	1	1
SRU 8	6	3	2	1
SRU 9	4	2	1	1
SRU10	2	1	1	0
SRU11	6	3	2	1

TOT INVESTM. = 527965 AVAILABILITY = 0.114

Reallocation of the inventory improves the obtained effectiveness slightly. For example, for an investment of $1,560,000, inventory reallocation improves A_o from 21.8% to 24.5%, but the obtained results are still unacceptable. In curve #4 (Figure 6-4) "jumps" are found for investments of $250,000, $930,000, and $970,000, approximately. These jumps are explained by the fact that at these investments the optimization process requires additional resources for the procurement of LRU's. These resources are partially obtained by reducing the invesmtent in SRU's. For the first scenario (curve #1, Figure 6-5), this action results in an increase of A_o. But when it turns out that $MTBF_o = MTBF_D/4$, procurement of more LRU's and fewer SRU's leads to a lower probability of an operational LRU being available given a demand, thus lowering A_o. In addition, some SRU's are shifted from the intermediate to the depot level, where they turn out to be less effective. As soon as the optimization process abandons this course of action and starts increasing the number of SRU's procured, A_o improves continuously. A similar phenomenon to the one described above was found for a different sytem, as well [Ref. 19]. In that case, because the number of systems was lower, the "jumps" revealed were significantly higher.

6.6.1.5. Summary of Scenarios

The four scenarios described above are summarized in Table 6-15. The impact of MTBF on investment in initial procurement of spares is illustrated in Figure 6-6 for an approximate A_o of 97.0%. In this figure, $MTBF_o$

Table 6-15

Summary of IIPS and A_o for the Four Scenarios (OPUS-VII)

Scenario	Initial Investment ($) Available	Initial Investment ($) Utilized	A_o (%) Achieved	Additional Investment Needed ($)	A_o (%) Achieved
1	528,000	528,000	97.5	0	97.5
2	528,000	520,500	23.0	2,000,000	96.9
3	528,000	490,000	59.5	234,000	97.4
4	528,000	528,000	11.5	2,000,000	96.9

varies between one fourth and twice $MTBF_D$, and the function is approximated by a continuous curve. The figure demonstrates that a decrease in MTBF causes an increase in the required IIPS, which becomes steeper when $MTBF_O < MTBF_D/2$.

The analysis in this section demonstrates the significant impact MTBF has on initial procurement of spares. As a consequence, one should seriously consider what actions might be taken to assure that $MTBF_D$ will also be achieved in the operational environment. This may be done in various ways, such as by means of a reliability warranty in the acquisition contract or through redesign of some components of the system. Both methods can reduce the uncertainty with regard to $MTBF_O$ and save on IIPS. Independent of the actions taken to assure an acceptable $MTBF_O$, an adequate model for the evaluation of initial procurement of spares should be available to the user, otherwise, any decision obtained in this matter is far from being optimal and results in a waste of resources.

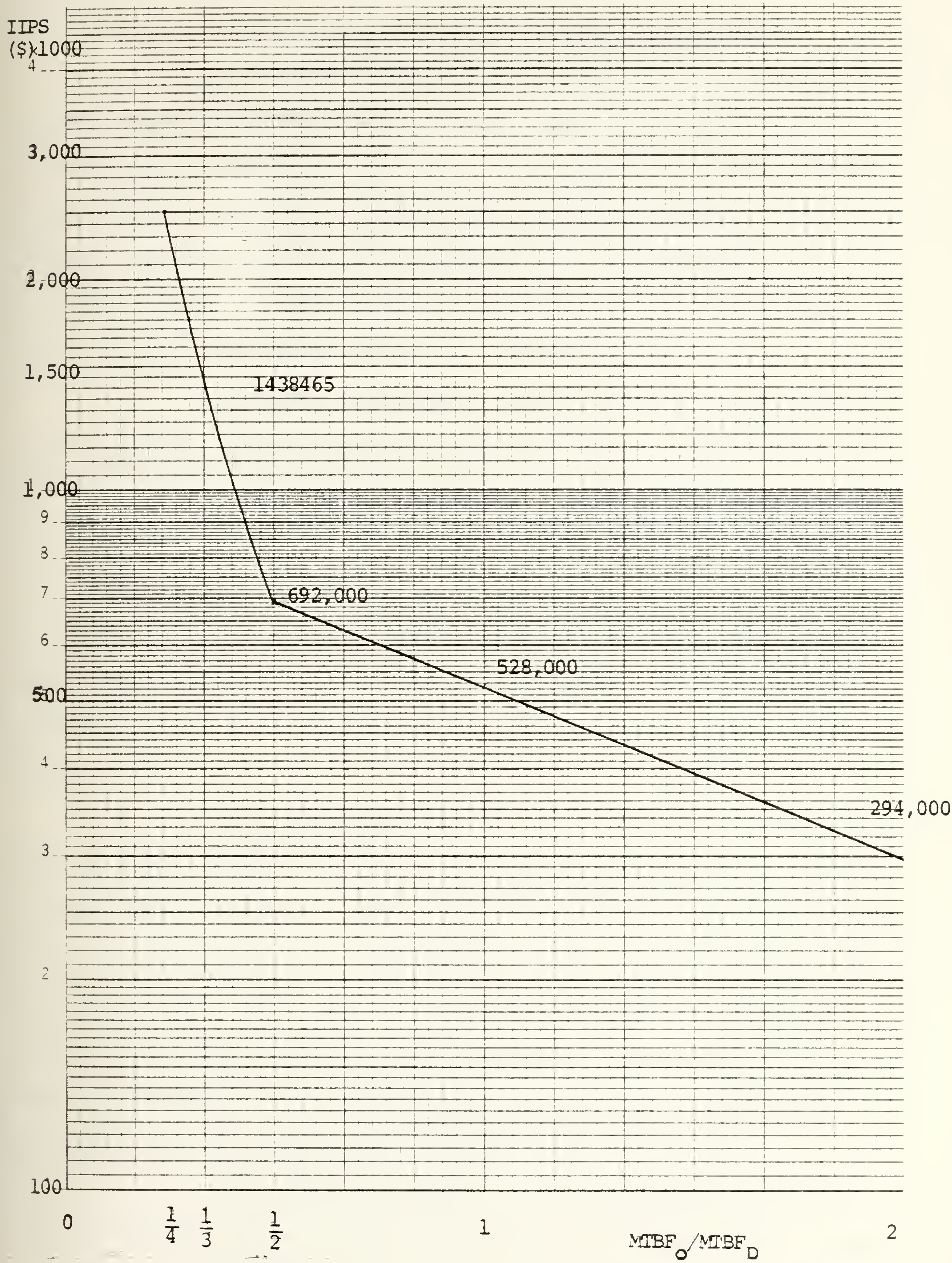

Figure 6-6. IIPS as a Function of MTBF for $A_o \approx 97\%$

6.6.2. The Impact of MTTR on Initial Procurement

The active repair time (MTTR) at organizational level is an important factor, which directly affects A_o of the system (Section 3.2.2). Due to the fact that MTTR in the operational environment ($MTTR_o$) may be up to several times higher than the MTTR value predicted by the manufacturer or resulting from a maintainability demonstration ($MTTR_D$) [Ref. 9], this variable has been chosen for investigation.

As shown previously, an A_o of 97.5% can be obtained for an IIPS of 528,000 (Table 6-4). In addition to this case, two cases are investigated. First, $MTTR_D$ is changed to 2.6 hours ($MTTR_o = 2 \times MTTR_D$). Second, $MTTR_D$ is changed to 5.2 hours ($MTTR_o = 4 \times MTTR_D$). In the first case, an A_o of 97.5% is obtained for an IIPS of $553,000 (4.7% increase in IIPS with respect to the basic version which is a moderate change). Table 6-16 presents inventory data and A_o for this case.

In the second case, an A_o of 97.5% is obtained for an IIPS of $803,000 (52.1% increase in IIPS with respect to the basic version). The increase in IIPS is mainly caused by the larger quantities of LRU's procured, primarily for the organizational level (only a few LRU's are procured for the other maintenance levels). The change in the quantity of SRU's procured is less significant. Inventory data and A_o for this case are presented in Table 6-17.

The impact of MTTR on IIPS is clearly revealed from the second case. Thus, an increase of MTTR at the lowest

Table 6-16

Inventory Data and A_o for $MTTR_o = 2 \times MTTR_D$

DENOM	TOTAL	DEP	IN1	IN2
LRU 1	5	0	3	2
LRU 2	9	0	5	4
LRU 3	4	0	2	2
LRU 4	5	0	3	2
LRU 5	5	0	3	2
LRU 6	25	17	5	3
SRU 1	15	10	3	2
SRU 2	7	4	2	1
SRU 3	4	2	1	1
SRU 4	24	16	5	3
SRU 5	4	2	1	1
SRU 6	14	8	4	2
SRU 7	3	1	1	1
SRU 8	6	3	2	1
SRU 9	4	2	1	1
SRU10	2	1	1	0
SRU11	6	3	2	1

TOT INVESTM. = 553615.0 AVAILABILITY = 0.97557

Table 6-17

Inventory Data and A_o for $MTTR_o = 4 \times MTTR_D$

DENOM	TOTAL	DEP	IN1	IN2	16× MN1	8× MN2
LRU 1	6	0	3	3	0	0
LRU 2	36	0	7	5	1	1
LRU 3	5	0	3	2	0	0
LRU 4	15	0	4	3	0	1
LRU 5	7	0	4	3	0	0
LRU 6	29	21	5	3	0	0
SRU 1	17	10	4	3	0	0
SRU 2	8	4	2	2	0	0
SRU 3	4	2	1	1	0	0
SRU 4	26	16	6	4	0	0
SRU 5	5	2	2	1	0	0
SRU 6	16	8	5	3	0	0
SRU 7	3	1	1	1	0	0
SRU 8	8	3	3	2	0	0
SRU 9	5	2	2	1	0	0
SRU10	3	1	1	1	0	0
SRU11	7	3	2	2	0	0

TOT INVESTM. = 803245.0 AVAILABILITY = 0.97486

maintenance level of the organization can cause a need for much higher spending on the spares initially acquired.

For A_o equal to 97.5%, the required initial investment in spares as a function of MTTR is presented in Figure 6-7. The function increases exponentially with MTTR.

The impact of MTTR on IIPS implies that precautions should be taken by the customer to ensure that $MTTR_o = MTTR_D$. Some ways to achieve this may be by using a maintainability warranty in the acquisition contract, emphasizing the training given to the maintenance personnel at the organizational level, and procurement of adequate tooling and test and support equipment.

6.6.3. The Impact of TAT at Depot Level Upon Initial Procurement of Spares

The turn-around time at depot level affects WT, and therefore, A_o. TAT at depot level (TAT DL) is normally the largest of the time elements of the repair cycle (Section 3.2.1). It is possible for the support organization to control this variable to some extent. To check its impact on initial procurement of spares, TAT DL was varied between 720 and 24 hours (assuming it can be cut down to this low value by implementing priority/emergency procedures in the organization). The required investment in spares as a function of TAT DL is illustrated by Figure 6-8. The curve reveals that when TAT DL is lowered to 24 hours, a saving of approximately $100,000 (19%) in the initial procurement of spares is gained. This reduction of TAT DL is not always easy to achieve because

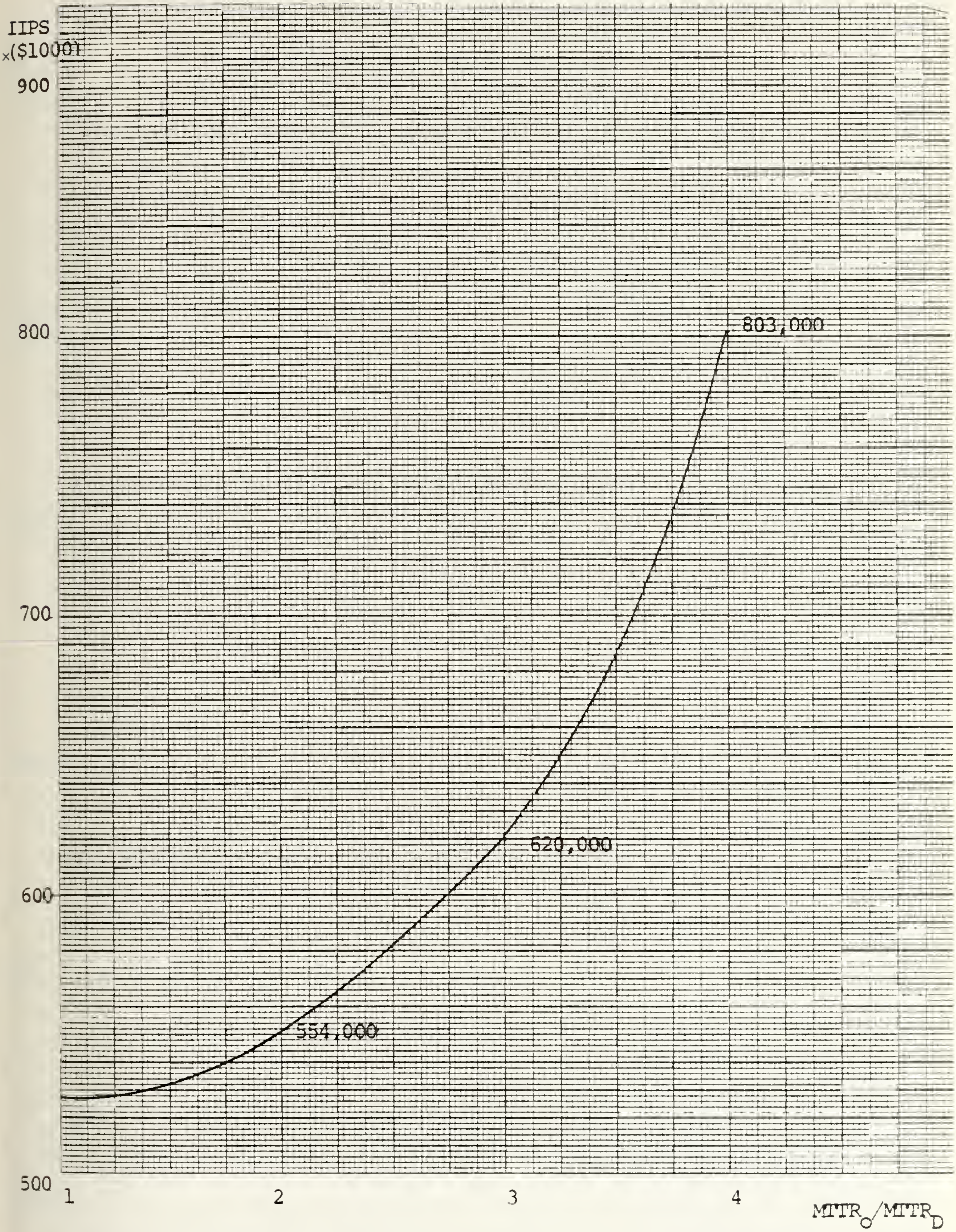

Figure 6-7. IIPS as a Function of MTTR for A_O = 97.5%

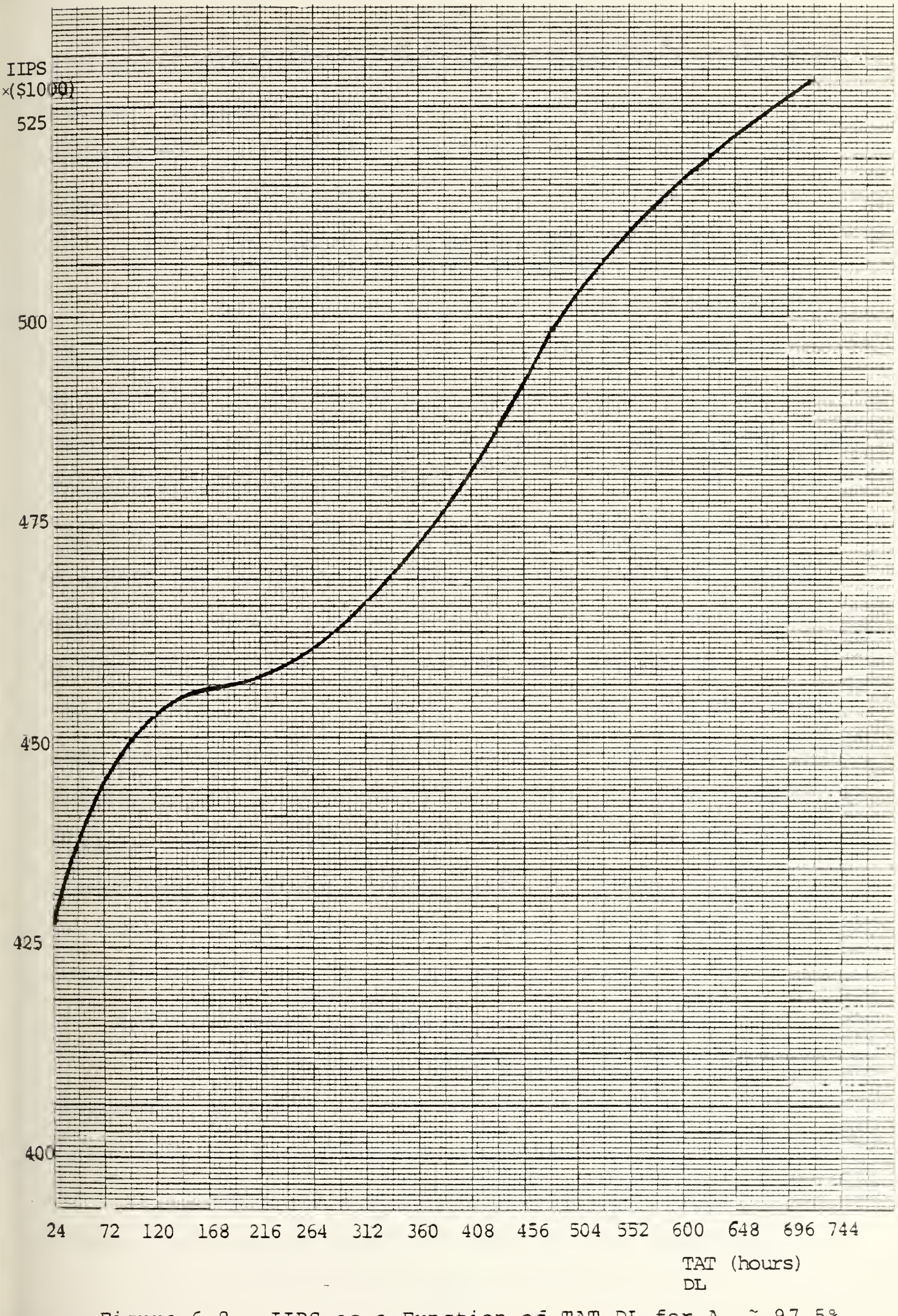

Figure 6-8. IIPS as a Function of TAT DL for A_o ≈ 97.5%

of existing constraints in the support organization (manpower, workload, emergency situations, travel distances, and budgetary limitations), but changing TAT DL is a possible course of action to be considered.

6.6.4. The Impact of Organizational Structure Upon Initial Procurement of Spares

To illustrate one of the trade-off possibilities between initial procurement costs and organizational characteristics, the number of intermediate level sites is reduced from two to one. This change is performed under each of the following two assumptions:

a) The average transportation time (round trip) between an operational site and the intermediate level site remains unchanged (2 hours). A net saving of $75,000 (14%) in IIPS is obtained by eliminating an intermediate level site.

b) Assuming that the average distance between operational sites and intermediate level is increased when the number of IL sites is cut to one, the transportation time is changed to 12 hours. The initial investment required for spares jumps to $889,000, an increase of $436,000 (or 83%).

The examples above illustrate the impact of the organizational structure on the initial investment in spares.

6.6.5. Summary, Initial Procurement of Spares

Much emphasis has been paid to the initial procurement of spares, mainly because it is normally a significant part of LSC and because essential savings are obtainable, if a scientific approach is adopted. But this cost element is still only a part of LSC, and to minimize the

investment in spares for a required value of A_o should not be a goal in itself. The objective must be to find the lowest LSC alternative (Section 3.4).

6.7. LIFE SUPPORT COSTS

6.7.1. <u>The Impact of MTBF Upon LSC</u>

For investigation of the impact of selected variables upon LSC, the models are used as illustrated by Figure 6-9.

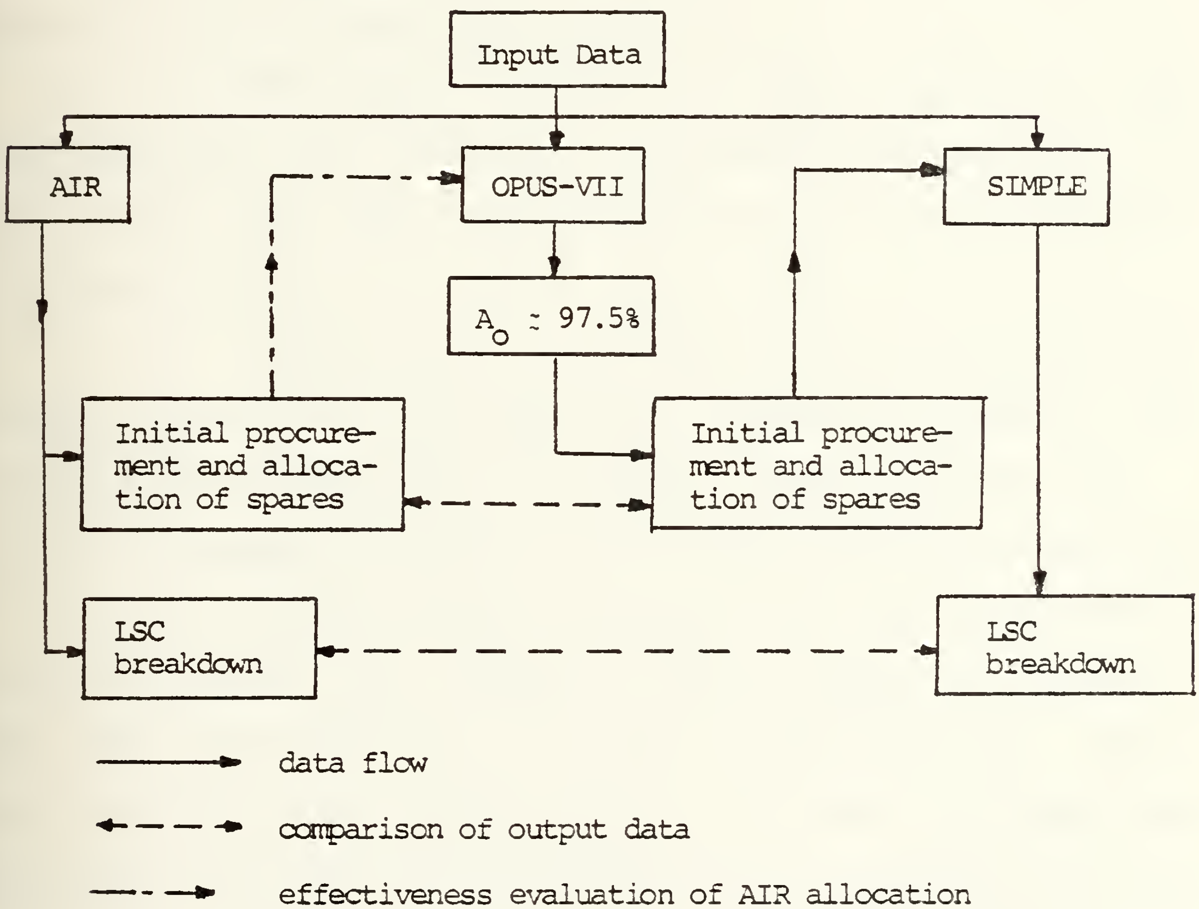

Figure 6-9. Use of Models for LSC Analysis

The initial procurement cost computed by SIMPLE is based upon OPUS-VII and an operational system availability of 97%. When one or more of the cost categories (Table 6-3) are unaffected by the variable being changed, these cost categories are not discussed. The variables entering the analysis are varied one at a time while the "basic" values (Appendix F) are used for variables not affected by this change.

The first variable in the sensitivity analysis is MTBF. For all LRU's and SRU's, MTBF is changed in steps from 0.25 to 2.0 times the basic value.

The results are found in Table 6-18 and for the more important cost categories illustrated in Figure 6-10. In this figure, only costs accounting for 10% or more of LSC are included.

Comparing the cost curves obtained from AIR and SIMPLE, significant differences are revealed in inventory and maintenance manpower costs, but having compensated for the factors discussed in Section 6.5, the cost curves are identical.

As illustrated by Figure 6-10, LSC is heavily affected by MTBF. The increase in LSC is especially steep when MTBF decreases below 0.5 times the expected value. The main reason for this is the effect a lower MTBF has upon inventory costs (Section 6.6.1), manpower, and transportation costs.

The total effect MTBF has on LSC illustrates the importance of adequate planning and conduction of reliability demonstrations, so that they are more reflecting what can be expected in the operational environment.

Table 6-18

LSC as a Function of MTBF ($1000)

MODEL	COST CATEGORY	2×MTBF	MTBF	MTBF/2	MTBF/3	MTBF/4
	LSC	2307	3992	6609	9352	12149
	Manpower	349	697	1395	2113	2789
AIR	T&SE	353	353	353	353	353
	Inventory	911	2091	3698	5403	7220
	Training	496	496	496	496	496
	Transport.	153	307	614	930	1227
	Other Costs	44	48	53	57	63
	LSC	3436	4667	6826	9566	12618
	Manpower	1644	2035	2816	3598	4379
SIMPLE	T&SE	356	356	356	356	356
	Inventory	1000	1694	2779	4445	6426
	Training	194	194	194	194	194
	Transport.	148	294	587	879	1172
	Other Costs	94	94	94	94	94

6.7.2. The Impact of MTTR Upon LSC ($1000)

The mean active repair time (MTTR) at organizational level is increased to 2, 3, and 4 times its basic value. The impact upon LSC and its components is shown in Table 6-19.

The only significant impact MTTR has on LSC when computed by AIR is the change in manpower cost of active repair time at the lowest level of the support organization. Computed by SIMPLE, this cost element increases by the same amount even if the calculation of manpower costs is based upon total time per corrective maintenance task. The reason for this is that it is assumed that other time elements associated

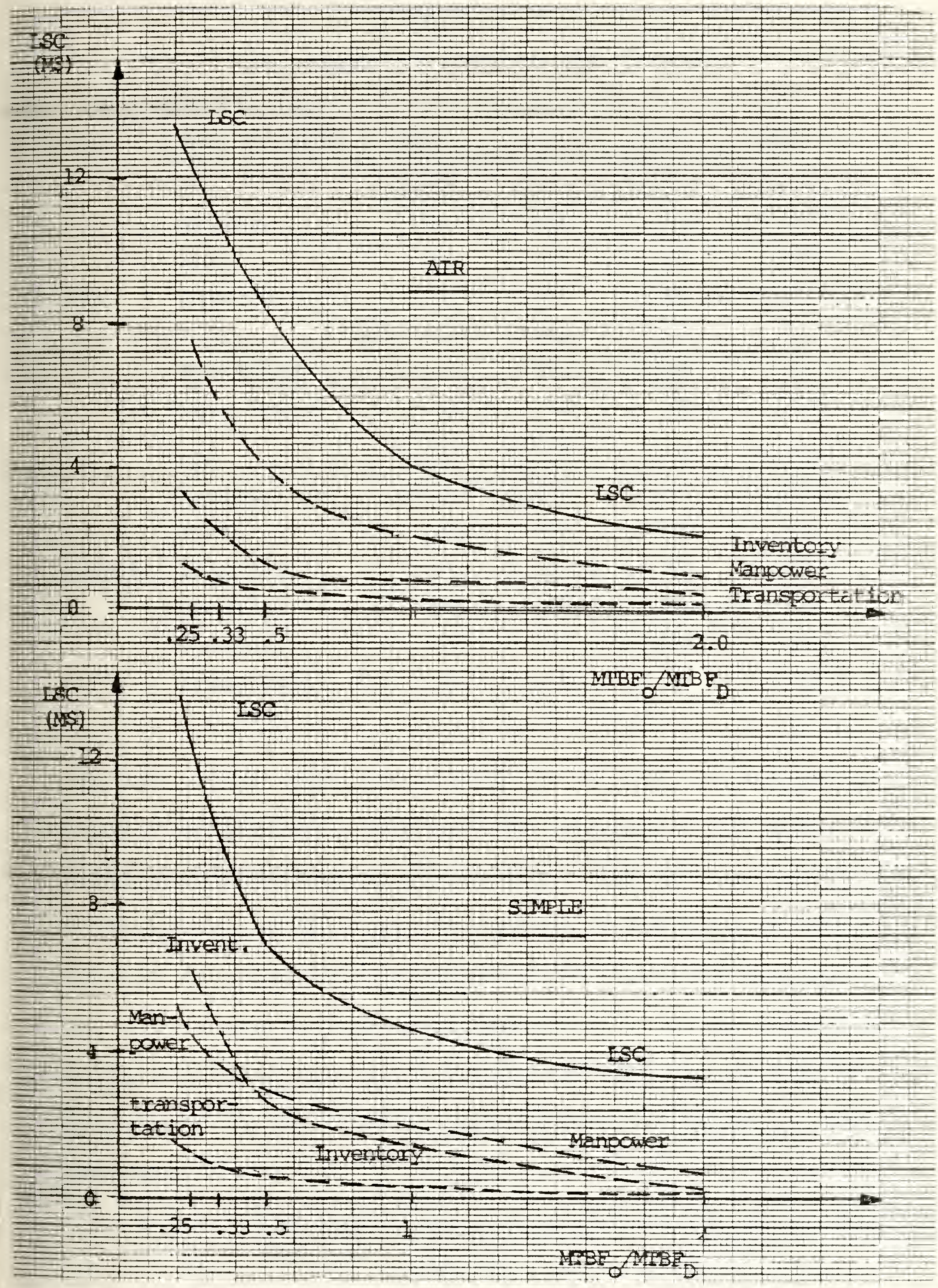

Figure 6-10. LSC as a Function of MTBF

Table 6-19

The Impact of MTTR on LSC ($1000)

MODEL	COST CATEGORY	MTTR×1	MTTR×2	MTTR×3	MTTR×4
	LSC	3,992	4,103	4,213	4,324
	Manpower	697	808	918	1,029
	T&SE	353	353	353	353
AIR	Inventory	2,091	2,091	2,091	2,091
	Training	496	496	496	496
	Transport.	307	307	307	307
	Other Costs	48	48	48	48
	LSC	4,667	4,805	4,984	5,310
	Manpower	2,035	2,147	2,259	2,371
	T&SE	356	356	356	356
SIMPLE	Inventory	1,694	1,720	1,787	2,001
	Training	194	194	194	194
	Transport.	294	294	294	294
	Other Costs	94	94	94	94

with the repair task (Section 3.3.1.1) are unaffected by MTTR. Computed by OPUS-VII, the initial investment in spares is a function of MTTR (as it should be). For the case where MTTR is multiplied by four an additional investment in spares of $336,000 is necessary to maintain the required availability. The total value of the additional cost is 13.8% of the expected LSC, a change which should be included in the estimated future cost if the maintainability demonstration is well conducted.

6.7.3. The Impact of Organizational Structure and TAT DL Upon LSC

To demonstrate the impact of organizational characteristics on LSC, the following alternatives are examined:

1) The number of intermediate level sites is reduced from two to one,

2) the depot level is eliminated, and

3) all LRU's and SRU's are repaired at depot level.

6.7.3.1. One Intermediate Level Site Only. Different Transportation Times.

For this maintenance alternative, LSC is computed for unchanged and two, four, and six times higher average transportation time between the operational sites and the intermediate level site.

LSC computed by AIR is unaffected by changes in the transportation time. When one intermediate level site is eliminated, the only changes in LSC computed by AIR are that the cost of test and support equipment is reduced by $84,000 and inventory entering and holding cost is reduced by $4,000.

Computed by OPUS-VII, the initial investment in spares is heavily affected by the transportation time. In SIMPLE, the calculation of transportation cost is based on an average distance between the levels of the support organization and a cost per mile. The change in transportation time is assumed to be caused by the fact that elimination of an intermediate level site will result in a larger average distance between the maintenance levels involved. Therefore, this input to SIMPLE is changed in accordance with the transportation time. The changes in LSC and the cost categories affected (computed by SIMPLE) are illustrated in Table 6-20 (Manpower costs are $2,034,700 for all alternatives).

Table 6-20

Changes in Support Costs (×$1000), One Intermediate Level, Different Transportation Times

Cost Category	Transportation Time 2 hours	4 hours	8 hours	12 hours	Basic Version
LSC	4,473	4,548	4,902	5,115	4,667
T&SE	271	271	271	271	356
Inventory	1,599	1,619	1,907	2,054	1,694
Training	185	185	185	185	194
Transport.	294	347	413	478	294
Other Costs	91	91	91	91	94

The changes in cost of test and support equipment, training, and other (documentation) costs are obtained in the model by eliminating the share of an intermediate level site from these cost categories.

Concerning inventory costs, the entering and holding cost is reduced by $5,000. The rest of the effect is caused by the change in the initial investment in spares. The possible advantages of having a "central" intermediate level are seen from the fact that even when the transportation time is doubled the resources initially required for spares are lower than if two intermediate level sites are operated. For higher transportation times, the increase in inventory and transportation cost makes it not cost-effective to have only one intermediate level site.

6.7.3.2. All LRU's and SRU's Repaired at Intermediate Level

In this case, it is assumed that the technicians at the intermediate level have attended the

training courses which normally are required for depot level personnel, that relevant documentation is procured, and that piece parts needed for repair of SRU's are stocked at both intermediate level sites. The results (with the output data for the basic version) are illustrated in Table 6-21.

Table 6-21

LSC (×$1000), All Models Repaired at Intermediate Level

COST CATEGORY	AIR Basic Data	AIR No Depot Level	CPUS-VII and SIMPLE Basic Data	CPUS-VII and SIMPLE No Depot Level
LSC	3,992	4,146	4,667	4,418
Manpower	697	503	2,035	1,841
T&SE	353	293	356	293
Inventory	2,091	2,644	1,694	1,915
Training	496	532	194	196
Transport.	307	129	294	79
Other Costs	48	45	94	93

This repair policy is more expensive when computed by AIR and less expensive when computed by SIMPLE than the repair policy used in the other sub-sections of this chapter. For both models, the manpower costs are reduced by approximately $200,000 (due to a lower hourly rate at intermediate than at depot level) and so is the transportation cost. The increase in inventory costs (computed by AIR) is mainly caused by a higher scrap and materials rate for intermediate than for depot level. The increase in inventory cost (computed by SIMPLE)

is mainly due to a higher initial investment in spares. The short transportation time (2 hours) and the relatively short administrative delay time (84 hours) at intermediate level make OPUS-VII suggest that 93.5% of the initial investment in spares are used for LRU's procurement.

6.7.3.3. All LRU's and SRU's are Repaired at Depot Level

It is assumed that even if no repair takes place at intermediate level, the two sites can still be used as stockage facilities. Failed modules are sent directly from organizational to depot level. LSC and its breakdown are illustrated in Table 6-22.

Table 6-22

LSC (×$1000), All Modules Repaired at Depot Level

COST CATEGORY	AIR		OPUS-VII and SIMPLE	
	Basic Data	Repair Depot	Basic Data	Repair Depot
LSC	3,992	5,034	4,667	5,234
Manpower	697	793	2,035	2,162
T&SE	353	289	356	282
Inventory	2,091	3,346	1,694	2,251
Training	496	292	194	176
Transport.	307	268	294	272
Other Costs	48	47	94	90

The higher labor costs are caused by the higher hourly rate at depot than at intermediate level.

Computed by OPUS-VII, the resources required for initial provisioning of spares are $1,100,000. The long administrative delay time at depot level (720 hours) becomes the most significant factor for the probability of spares being available (Section 3.2.2), and it is not longer cost effective to buy SRU's. Of the LRU's procured, 83% are stocked at the depot and the remaining at intermediate level sites.

The initial investment in spares computed by AIR is $2,150,000. These resources are almost equally divided between LRU's and SRU's, all stocked at the depot level. When the administrative delay time at the depot level is reduced, the only impact on LSC is the decrease in resources required for initial provisioning of spares, which is discussed in Section 6.6.3.

6.7.4. The examples of organizational and maintenance policy changes discussed above cover only several possible alternatives, but are illustrations of the type of analysis needed to obtain the lowest LSC (Section 3.4).

6.7.5. <u>The Impact of Some Other Variables on LSC</u>

6.7.5.1. Number of Systems in the Organization

The number of systems supported by the organization is changed in steps between 6 and 100. It is assumed that the average distance between the different levels of the support organization and the costs of training and test and support equipment per system are unaffected. Under these

assumptions, inventory is the only cost category for which the cost per system is affected by the number of systems.

The initial investment in spares per system is computed by OPUS-VII and by AIR. The results are illustrated by Figure 6-11. LSC and LSC per system are illustrated in Figure 6-12. LSC and LSC per system are higher when computed by SIMPLE than are the same costs computed by AIR. The main reason for this is that AIR does not include the cost of preventive maintenance.

6.7.5.2. Discount Rate

It is argued that once cost estimates have been generated they must be time-phased to allow for alternative patterns of expenditure [Ref. 4]. The time-value is obtained by computing the present value cost. The Department of Defense (DOD) currently uses a 10% discount rate and does not include the effect of inflation. Some organizations use a zero discount rate and others include a discount and an inflation rate as well. The intention is not to argue pro or con the present value approach but merely to illustrate the effect of using different discount rates. Figure 6-13 shows LSC for the numerical example used in this chapter as a function of the discount rate. As illustrated, use of a discount rate of 10% for this example will "reduce" LSC by more than 40% compared to its value if the present value approach is not used. Further, the figure illustrates that if high values of discount rate are used, inventory costs become a greater part

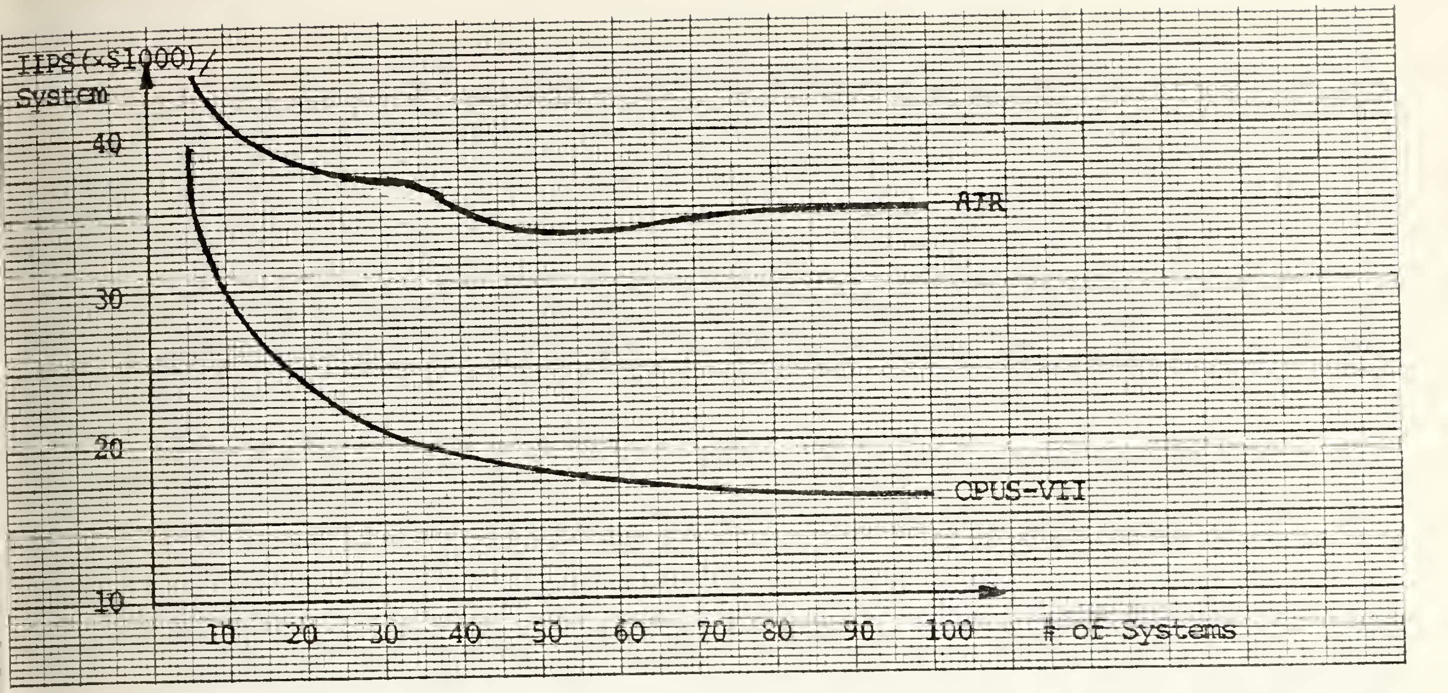

Figure 6-11. Initial Investment in Spares per System

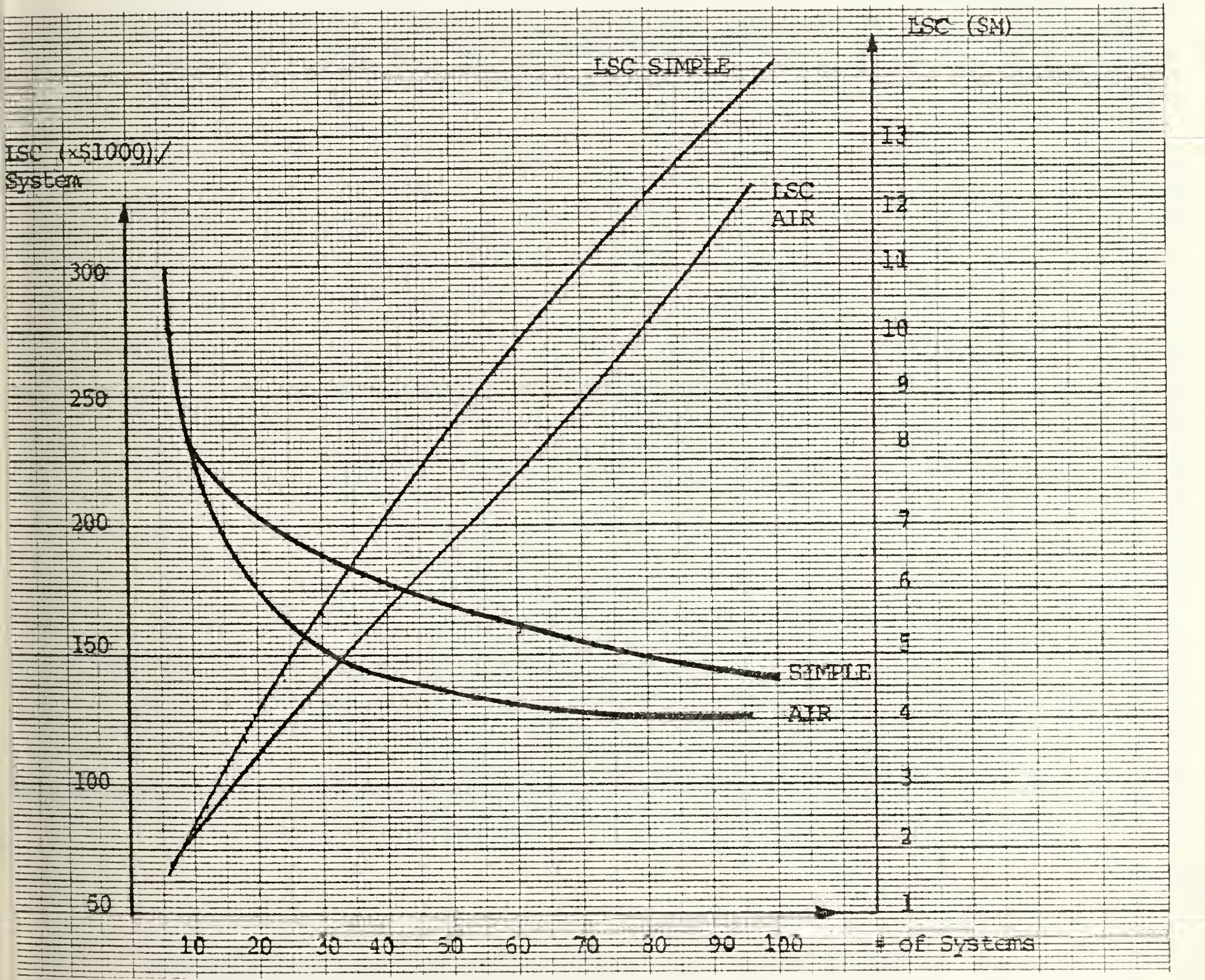

Figure 6-12. LSC and LSC per System as a Function of the Number of Systems

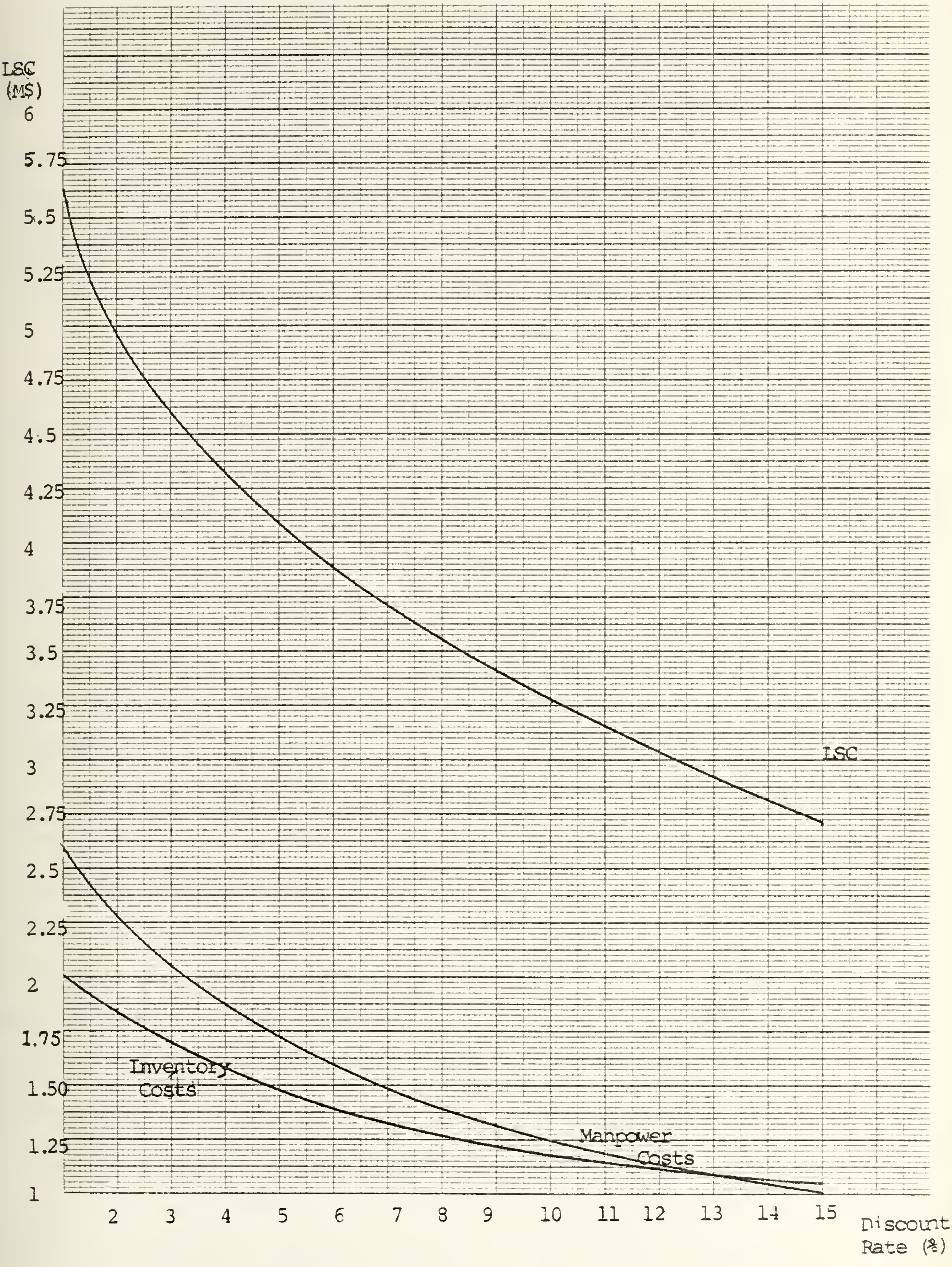

Figure 6-13. LSC as a Function of Discount Rate

of LSC than manpower costs. (The reason is the initial investment in spares which is in a "present value" form already.)

6.7.5.3. Assuming that the MTBF remains constant, the life cycle period is changed to 5, 10, and 20 years. Using a zero discount rate, LSC is (as expected) a linear function of the life cycle period. For this numerical example a 33% change of the use period changes LSC by 22%.

6.7.5.4. Additional Variables

An example of a variable heavily affecting LSC but not controllable by the military is labor rates. For the basic set of input data used in this chapter, maintenance manpower costs (computed by SIMPLE) account for more than 40% of LSC. (A 10% increase of labor rates will increase LSC by $203,000.)

The condemnation rate (the fraction of failed repairable modules for which repair is not cost-effective), together with MTBF, determines the replenishment procurement cost for repairable items which, in this example, accounts for 11% of LSC ($540,000). This variable is affected by such factors as system design (in modern electronic equipment, using circuit cards, welding can only be performed a limited number of times), packaging, handling, and transportation methods, and training and responsibility of operator and technical personnel. Thus, this cost can to some extent be controlled by the user.

6.7.6. Repair vs. Discard

The repair/discard decision curve is easily obtained from SIMPLE due to the built-in procedure which

calculates the delta costs (repair minus discard cost) for each module. This curve is illustrated in Figure 6-14 (for an SRU with 10 peculiar piece parts and IIPS of $4000).

To verify the repair/discard decision curve, AIR was used (with modified input data, including a specific SRU unique to an LRU). The points at which the repair decision shifted to discard (or vice versa) were found by "trial and error" (the unit cost was varied around the expected value until the decision shifted fom "all dicard" to "repair starts").

As a result, an approximate repair/discard curve was obtained from AIR, which, as expected, lies slightly below the curve from SIMPLE (AIR favors repair due to manpower and inventory costs. Active repair time only and a low IIPS for SRU's are used). General repair/discard curves were found, for which unit cost is a function of the anticipated number of failures of a module during the life cycle. These curves (illustrated in Figure 6-15) are for SRU's which include zero to forty two peculiar piece parts and an IIPS of $2000 to $27,000. The lower curve is to be considered as the lowest limit for the repair choice to be adopted.

The impact of the following variables on the repair/discard decision was found to be as anticipated:

a) discount rate--changes delta-costs almost linearly.

b) MTTR--an insignificant change in delta-costs.

c) scrap rate--an insignificant change in delta-costs.

d) one intermediate level only--an insignificant change in delta-costs.

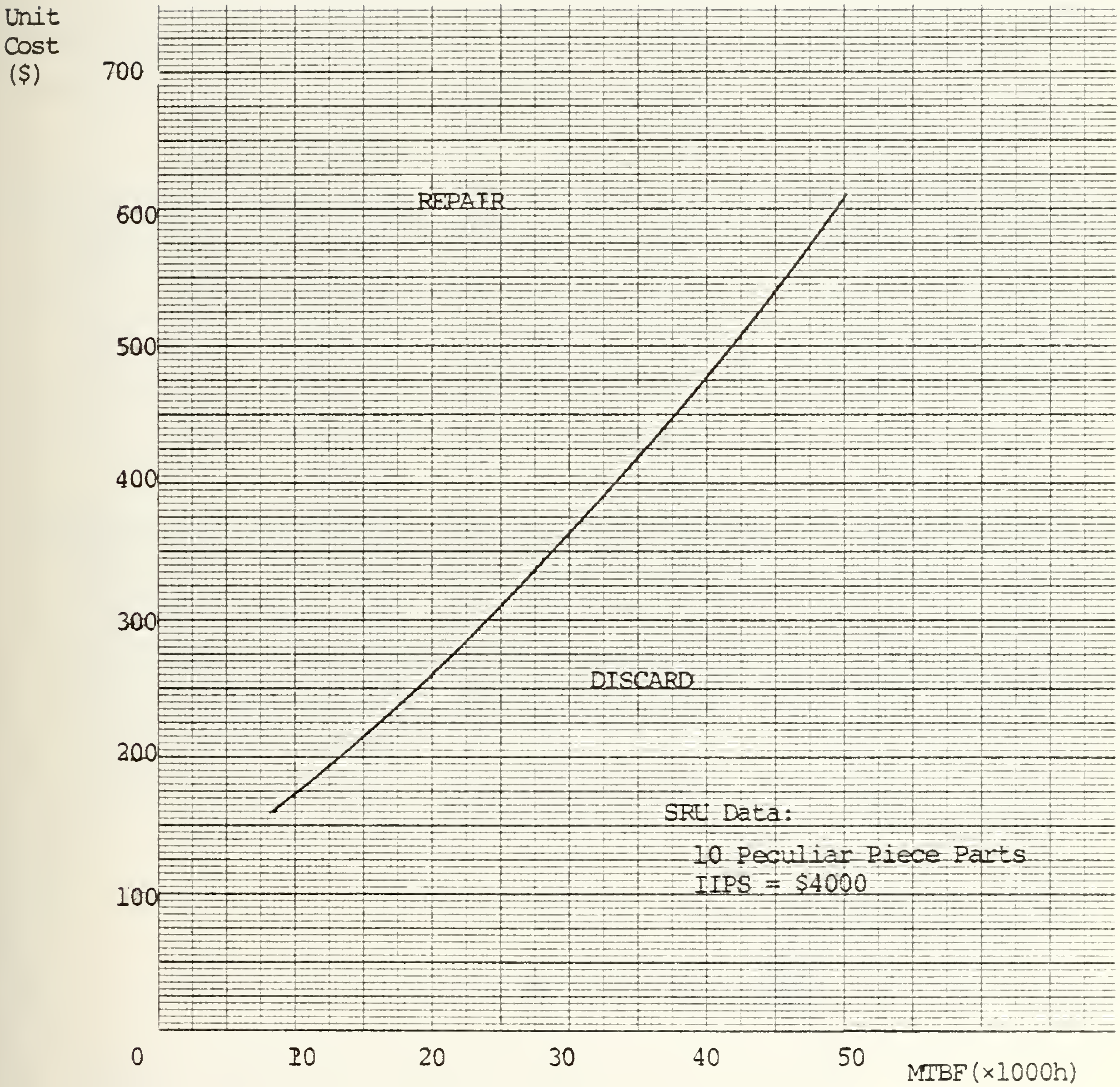

Figure 6-14. The Repair/Discard Curve (SIMPLE)

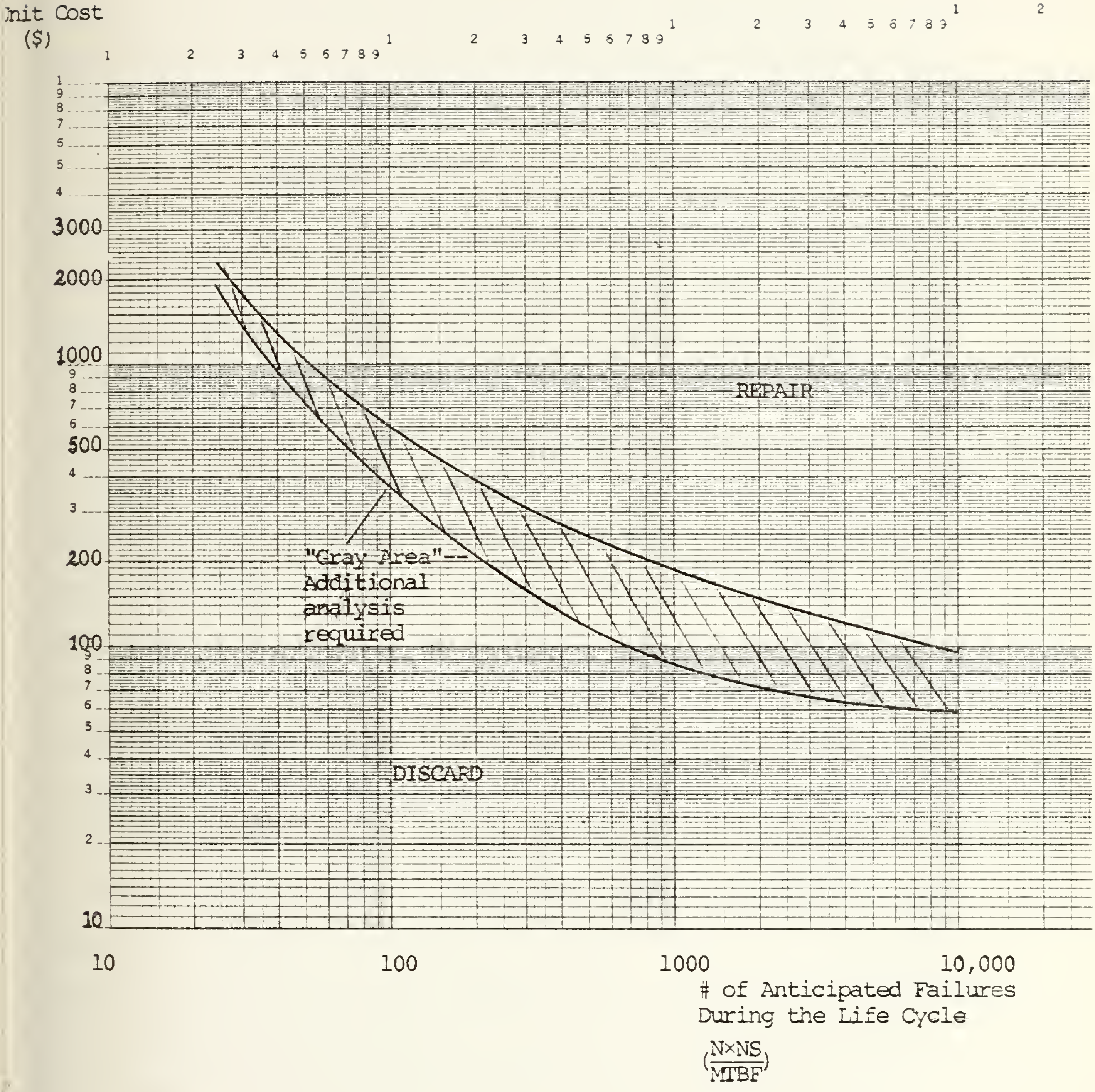

Figure 6-15. The General Repair/Discard Curve

e) transportation time--no general trend of change in delta-costs (a function of IIPS).

f) number of systems--when changed to 6, 12, and 18, a saving of \$140,000, \$51,000 and \$1,400 (respectively) in LSC was obtained due to modules for which the maintenance policy shifted from repair to discard.

6.7.7. Limited Resources for Initial Procurement of Spares

In reality, the initial procurement of spares is often performed under a budgetary constraint. For example, if only \$357,000 is available for the IIPS, the A_o obtained will be 82% only (in comparison with \$528,000 which enables an A_o of 97.5%). In this case, improvement of A_o may be attempted to be obtained by using only 23 operational systems instead of 24, and "canibalizing" the remaining system by using its modules as spare parts. Thus, one LRU (No. 4) and many SRU's are added to the inventory and A_o will increase from 82% to almost 85%. In this numerical example, the total operating hours obtained during the life cycle turn out to be lower with "canibalization" than without it (2,568,870 versus 2,585,952 hours) and the change is not worthwhile. But in other cases it may be a possible course of action to overcome the budgetary constraint, although it is not a solution easily acceptable by most organizations (usually the preference is to improve A_o by means of cutting down turnaround times or a priori decreasing the number of acquired systems to release more funds for spare parts).

6.7.8. The Cost of an Operating Hour

The calculation of LSC and IIPS for different levels of A_o enables the obtaining of the curve (Figure 6-16) which illustrates the cost of an operating hour as a function of IIPS. When appropriate, IIPS should be specified at a level which gives the lowest value of the cost of an operating hour during the life cycle. In this example, IIPS should be \$528,000 for which the cost of an operating hour is \$1.69. Cutting the resources for IIPS results in a significantly higher cost of an operating hour (as well as a lower A_o). On the other hand, higher resources for IIPS have a smaller impact on A_o and the cost per operating hour.

The significance of allocating sufficient resources for IIPS is illustrated by the figure.

6.7.9. Summary

The analysis in this chapter is based on a given system supported by a specified organization. Therefore, no general conclusions can be drawn. But, it is demonstrated that an efficient model for initial procurement and allocation of spares is required if a given operational availability is to be achieved for a minimum cost.

Figure 6-17 summarizes the impact of the various variables on LSC. For the example data used in this chapter, it is demonstrated that of the system characteristics explored, MTBF has the strongest impact on LSC.

No attempt has been made to find the lowest LSC alternative. But a twenty percent difference exists between

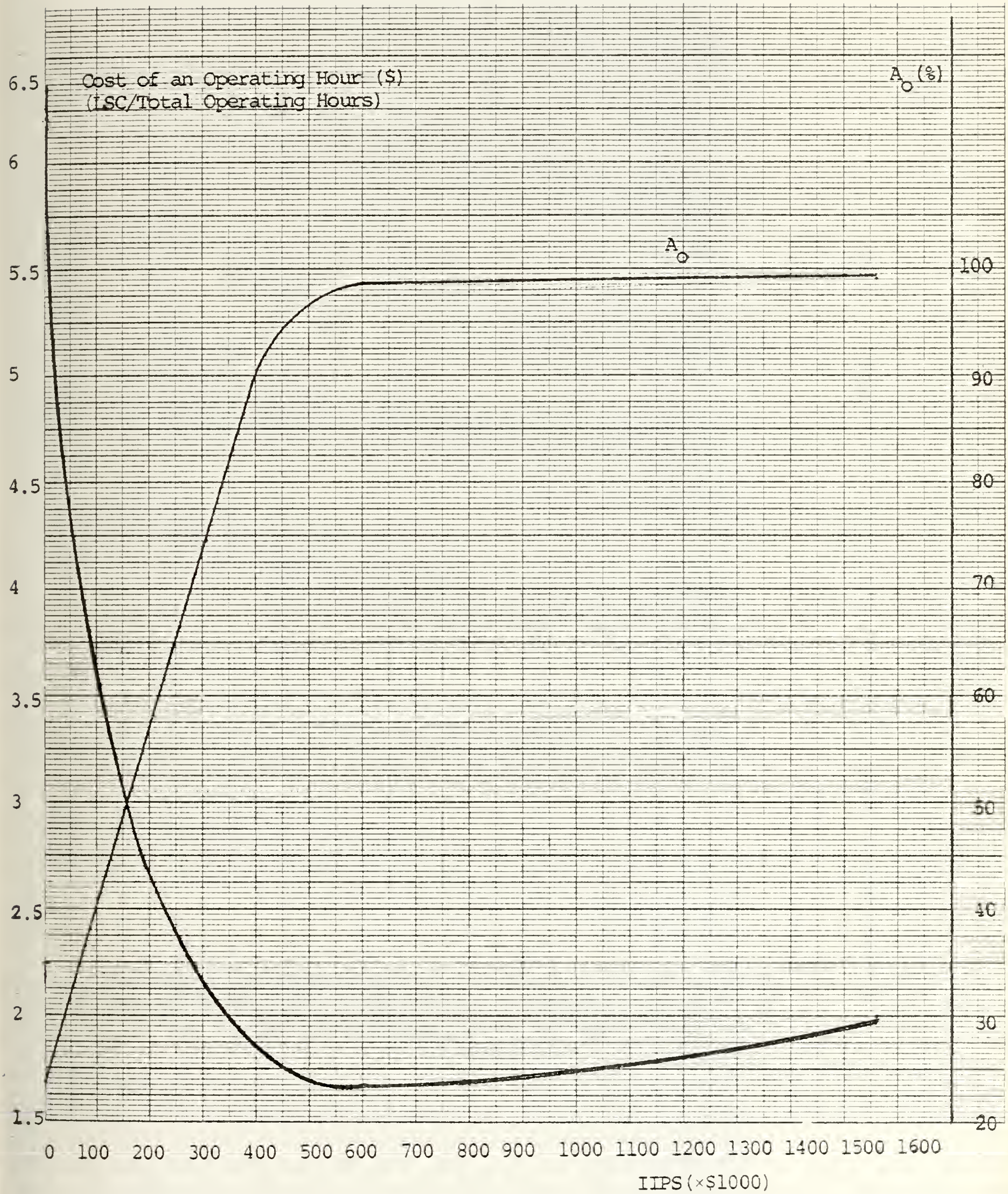

Figure 6-16. A_o and Cost of an Operating Hour as a Function of IIPS

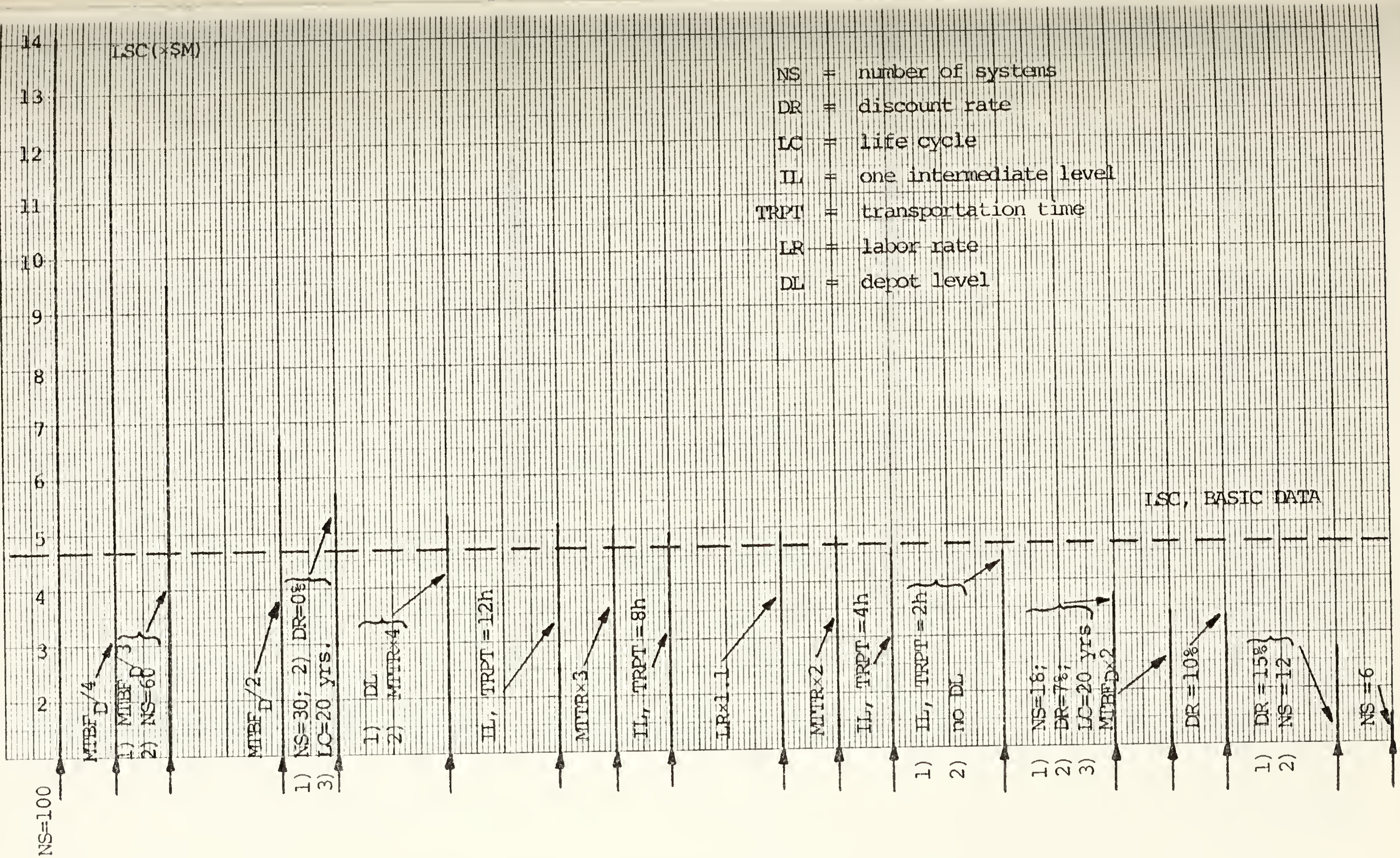

Figure 6-17. The Impact of Different Variables on LSC

the two maintenance alternatives: 1) all modules are repaired at depot, and 2) all modules are repaired at intermediate level sites. This illustrates the importance of an LSC analysis.

VII. SUMMARY AND CONCLUSIONS

7.1. SUMMARY

Two important factors in the procurement decision process are the Life Cycle Cost (LCC) and the System Effectiveness (SE) of the systems and equipments being considered. Life Support Cost (LSC) is a significant part of LCC, especially for small countries which buy equipment which has already been developed and produced by the larger industrial countries.

To determine the optimal LSC alternative, trade-off analyses must be performed. This is a complex task for which computerized models are necessary. For appropriate measures of effectiveness (MOE's), such models must have the ability to perform a repair/discard analysis and to determine the optimal initial procurement and allocation of spares.

Provisioning of spares is the most complex issue in the prediction of LSC. A provisioning model is necessary in order to obtain the minimum LSC alternative. When a provisioning model is available, useful estimates of LSC can be obtained by use of a simplified model, an approach which has been successfully adopted by the Swedish armed forces. SIMPLE, the model developed in this thesis, is an example of a simplified LSC model.

Two of the important LSC cost-drivers are the Mean Time Between Failure (MTBF) and the Mean Time to Repair (MTTR) of the modules of the failed system. These variables are sensitive

to the actual values obtained in the operational environment which may be several times worse than those predicted or demonstrated by the manufacturer.

7.2. CONCLUSIONS

Based on the model analysis and the numerical example, the following is concluded:

a) The support organization structure has a significant impact on all elements of LSC. Substantial cost savings are obtainable if the optimal level of repair and stockage policies are determined.

b) The system characteristics found to have the greatest impact on LSC are MTBF, MTTR, and the requirement for preventive maintenance. The impact of MTBF is stronger than that of MTTR.

c) Insufficient spares initially procured and allocated will significantly reduce the operational availability and increase the cost per operating hour.

d) Both the quantity and the optimum assortment of allocated modules (LRU's and SRU's) are sensitive to the value of MTBF. As a result, some modules which are cost-effective at one value may not be so for another value of MTBF.

e) All time elements of the repair cycle affect the provisioning of spares. The impact of a given time element is greater the lower the level at which it occurs in the support organization.

f) If provisioning is performed according to an accepted value of MTBF and it turns out that the actual MTBF is

substantially lower, the operational availability will become unacceptably low. Furthermore, the operational availability may decrease at some points with an increasing investment.

g) The modules which should be included in a detailed repair/discard analysis can be determined by use of a simple screening rule.

h) OPUS-VII has several MOE's and is an efficient model for the optimization of spares provisioning.

i) AIR is a useful model for repair/discard and LSC analysis. However, it does not have an appropriate MOE for optimal allocation of spare modules. It understates the cost by omitting the cost of preventive maintenance and portions of the actual repair time. The equation used for computation of training costs requires revision. The total effect is that the LSC computed by AIR is not as realistic as the value computed by SIMPLE/OPUS-VII.

j) SIMPLE is a useful model for estimating LSC, especially for comparison of systems already produced.

k) Compared to OPUS-VII, AIR invests almost twice as much in provisioning of spares, but the operational availability achieved is significantly lower. This is caused by the MOE used in AIR (95% fulfillment of requisitions). As a consequence, AIR stocks LRU's mainly at operational sites and SRU's at the depot level only. Although OPUS-VII may stock some LRU's at operational sites, it stocks LRU's primarily at intermediate level sites and it divides SRU's between the depot and intermediate level sites.

In addition to the above, to assure that the deviation between the expected and the actual values of MTBF and MTTR is kept at a minimum, the following actions are recommended:

a) Include reliability and maintainability warranties in the acquisition contract.

b) Provide adequate training of operating and maintenance personnel.

c) Consider design changes to modules which have a high failure rate.

d) Devote sufficient funds for test and support equipment.

APPENDIX A

SYSTEM LIFE CYCLE*

A.1. INTRODUCTION

A System's Life Cycle may be originated in one or more of the following ways:

a) As an outgrowth of a new need, based upon changed goals or missions, or a new threat revealed ("needs").

b) As a response to a new technologically feasible opportunity ("technology").

c) As a result of a deficiency in existing systems' capabilities ("system obsolescence").

The new system should be defined in terms of the mission, purpose, capability, schedule, and cost objectives, and not in hardware terms.

Different systems have different life cycles. They vary from three to five years for computers, 10 to 20 years for aircraft, and up to 20 to 30 years for ships. Between the two end points of a system's life, a number of periods exist, through which the system passes. In the grossest sense it may be defined as the Planning Period, the Acquisition Period, and the Use Period, each consisting of several phases (Figure A-1).

A.1.1. The Planning Period is the initial period in the system life cycle. During this period the need for the system is verified, system's concepts are formulated, and their feasibility and worthwhileness are established, leading to an output of system identification and requirements.

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*The material presented in this appendix has been abstracted from Reference 5.

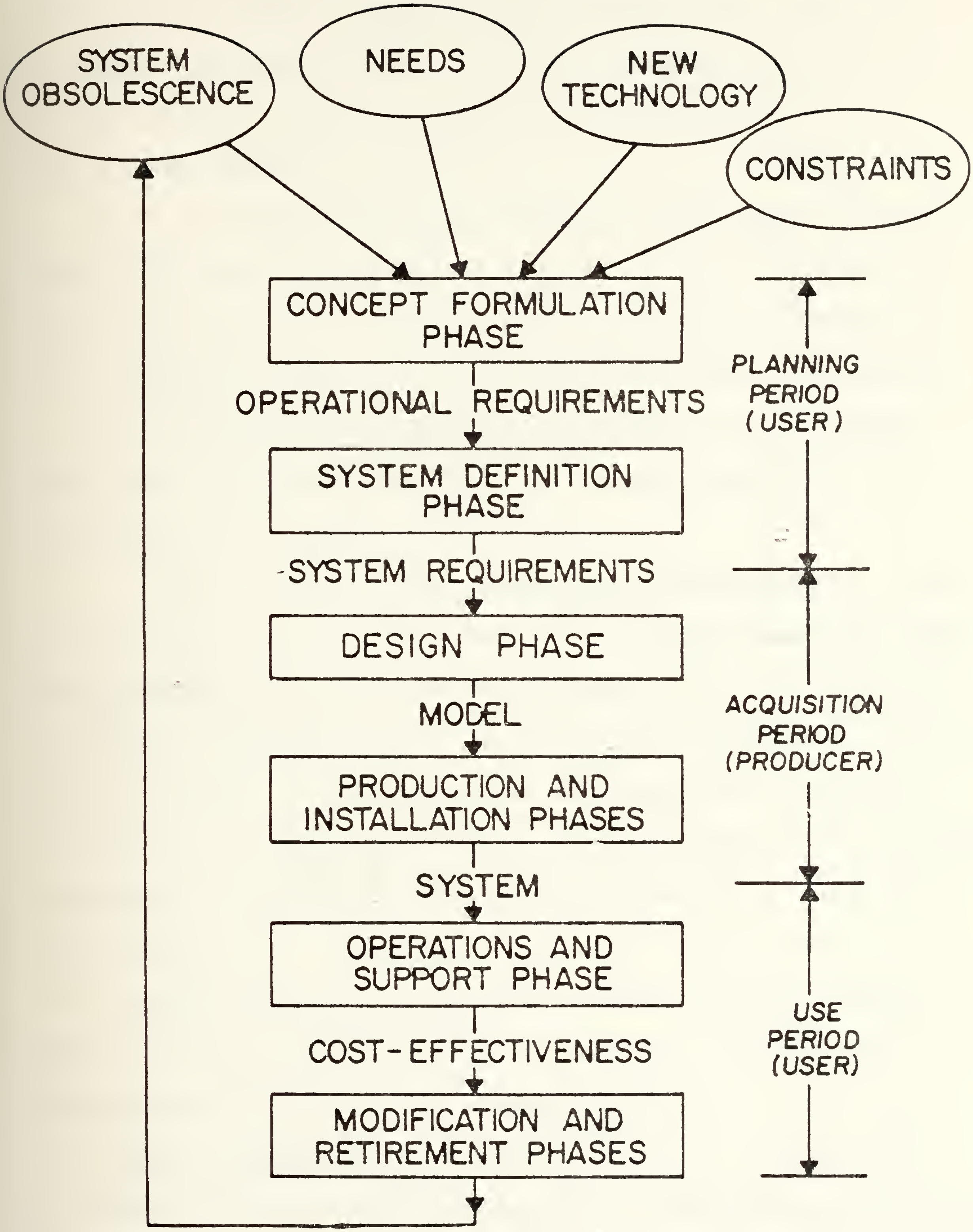


Figure A-1. System Life Cycle

Although the planning function is primarily the system user's responsibility (he is the one who specifies the needs, and is directly concerned with the resources available and the existing constraints), it should be carried-out with producer's assistance.

The Planning Period starts with input information about the needs, the resources available, the environment in which the system will operate, and the existing constraints. This information sets the bounds of the problem. The output is a set of system requirements for system design, derived from activities which comprise the Concept Formulation and System Definition phases (Figure A-1).

A.1.1.1. <u>The Concept Formulation Phase</u> is the initial phase of the system life cycle during which the feasibility of system operational requirements is identified and evaluated--technologically, economically, financially, legally and politically. An optimal system concept for performing the specified mission is considered, and justified for further development. The decisions are made based on the following activities:

a) <u>Mission Feasibility Studies</u>--analysis of the stated needs, synthesis of alternative missions, and analysis of these mission activities for feasibility.

b) <u>Preliminary Approach Studies</u>--detailed investigation of the system cost and effectiveness of alternative approaches for defining the best system concept possible subject to existing constraints.

c) System Development Planning--a management planning stage, justifying the further development of the approach adopted, with respect to resources required and available, time schedule, and risk involved. After this stage is completed, a final approval to proceed with system development is obtained. The primary activities of Concept Formulation Phase are illustrated in Figure A-2.

A.1.1.2. The System Definition Phase is used for refining the selected approach, and further consideration of technical, economic, and financial feasibility and risk. During this phase, system operational requirements are translated into a set of system design requirements, as a prerequisite for the engineering development effort.

The System Definition Phase consists of the following three stages:

a) System Functional Analysis--analysis of system operational requirements, identification of system and sub-system parameters, constraints and their relationships, establishment of cost-effectiveness criteria, and feasibility analysis.

b) System Design Concept Studies--formulation of initial system design concepts, first diagrammatic representation of sub-systems and their interfaces, and evaluation of alternative system design concepts (including trade-offs against design criteria and constraints).

c) System Requirements Specifications--transformation of the selected design concept into detailed system and sub-system

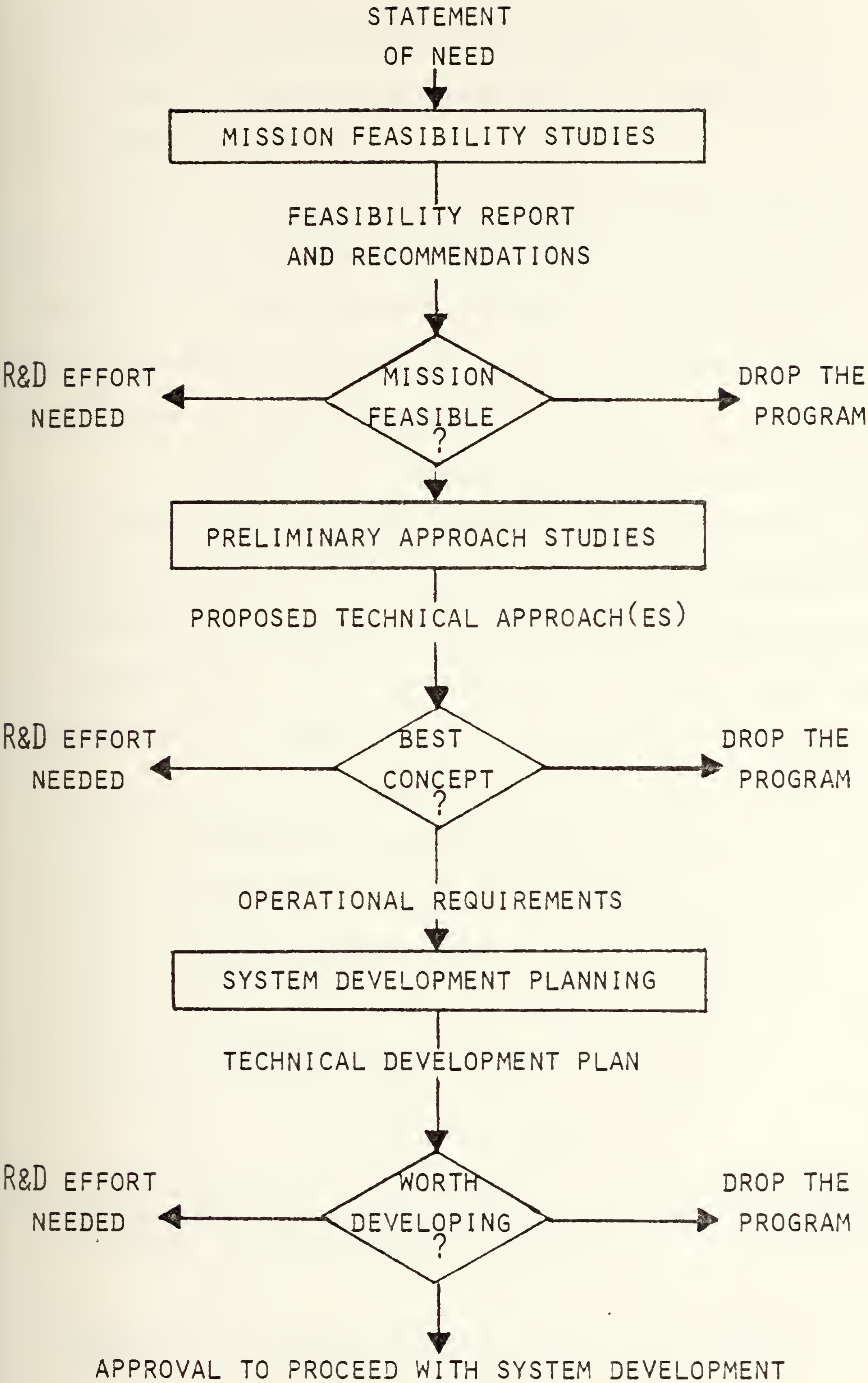


Figure A-2. Primary Activities of Concept Formulation

requirement specifications and management planning documents, to be used for development and design of the different indenture levels of the system.

A.1.2. The Acquisition Period is concerned with the design, test, evaluation, production, and installation of the system, and is the system producer's responsibility. This period includes three phases: the Design Phase, the Production Phase, and the Installation Phase.

A.1.2.1. Design Phase (RDTE--Research, Development, Test and Evaluation) encompasses that portion of the Acquisition Period during which major times and system design costs occur. Its output is a model, demonstrated and evaluated to optimally meet the requirements specified. The Design Phase consists of five stages, as illustrated in Figure A-3, below.

- PRELIMINARY DESIGN STAGE
- ENGINEERING DEVELOPMENT STAGE
- DETAIL DESIGN STAGE
- TEST AND EVALUATION STAGE
- PRODUCTION DESIGN STAGE

MODEL OF SYSTEM

(specifications for producing, installing, using, supporting and maintaining the system which optimally satisfies the recognized need)

Figure A-3. Design Phase Stages

a) Preliminary Design Stage--selection of one of the feasible design concepts for implementation, using sensitivity stability, compatibility, and state-of-the-art analyses, experimental laboratory work, and physical mock-ups.

b) Engineering Development Stage--intensive development and design of the system and sub-systems (investigation of packaging and configuration schemes, selection of parts and materials, provisions for test and support, and estimation of reliability and maintainability).

c) Detail Design Stage--consideration of details to the smallest part, performance of a statistical analysis to assure the design producibility, incorporation of logistic design considerations, as well as human factors, safety, and training, to assure that the design is operable, reliable, and maintainable. Various interface requirements are also checked (Figure A-4).

d) Test and Evaluation Stage--full performance of the prototype test model under service conditions. This stage includes operational suitability, reliability, and maintainability tests to evaluate system effectiveness under service conditions.

e) Production Design Stage--redesign activities, definition of production processes and tooling, and production and quality control tests, procedures, and equipment.

A.1.2.2. The Production Phase includes effectiveness factors, such as quality assurance, reliability, and reproducibility. Individual inspections and acceptance tests are made under various environmental conditions, and life tests are performed to provide a measure of reliability

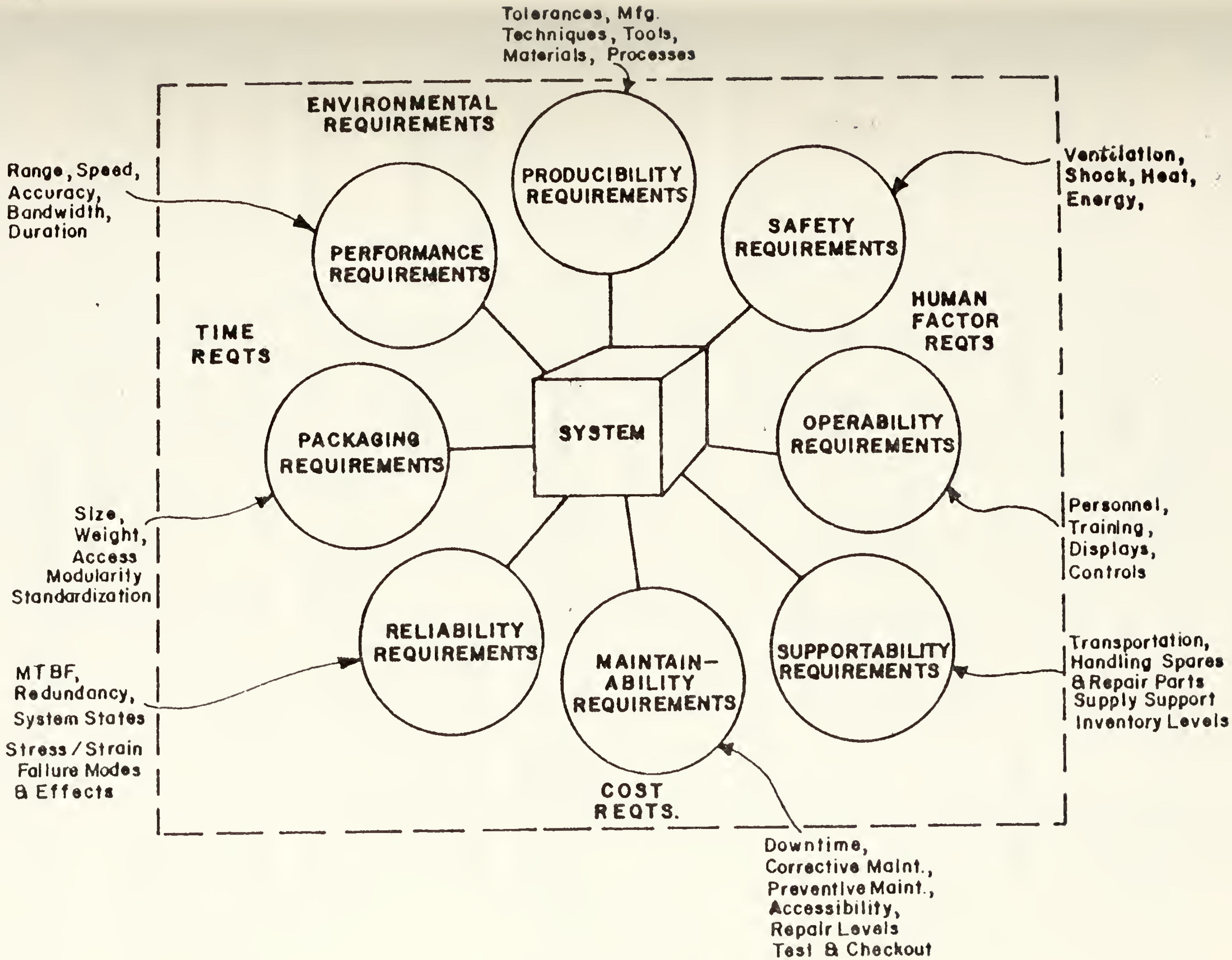


Figure A-4. The Framework of System Design

assurance. Marginal performance items and production tolerance effects are measured, resulting in design changes and improvements.

A.1.2.3. Installation Phase includes planning of facilities (space, power, water, cabling), logistics (support equipment, materials, supplies, spare parts and storage), test and checkout (equipment and personnel), and interface requirements. Only after installation, using all the required resources, the system exists as a complete entity, ready for use in an operational environment.

A.1.3. The Use Period is that period during which the system operates to fulfill the mission requirements for which it was designed and produced. This period consists of three phases: Operations and Support, Modification, and Retirement.

A.1.3.1. The Operations and Support Phase includes activities concerning provisioning, maintenance, support equipment, training, technical manuals, security requirements, and personnel (operating and technical).

A.1.3.2. Modification Phase includes the engineering changes made to the system, as a consequence of problems detected during actual use, or new or changing requirements that have to be met. These modifications are undertaken to minimize early obsolescence and to keep the system operational for longer periods.

A.1.3.3. Retirement Phase occurs at the final stage of system life cycle, when it is no longer cost-effective to operate and support. This phase concludes the life cycle

of the existing system, and leads to requirements for a new system which will fulfill different needs and requirements.

A.2. SYSTEM-LOGISTIC SUPPORT INTERFACES

The functions involved with the system life-cycle are closely related to logistic support. Figure A-5 illustrates the system development process, and conveys the major interfaces between prime mission equipment and logistic support. The presentation represents a general process covering basic engineering and logistic support considerations.

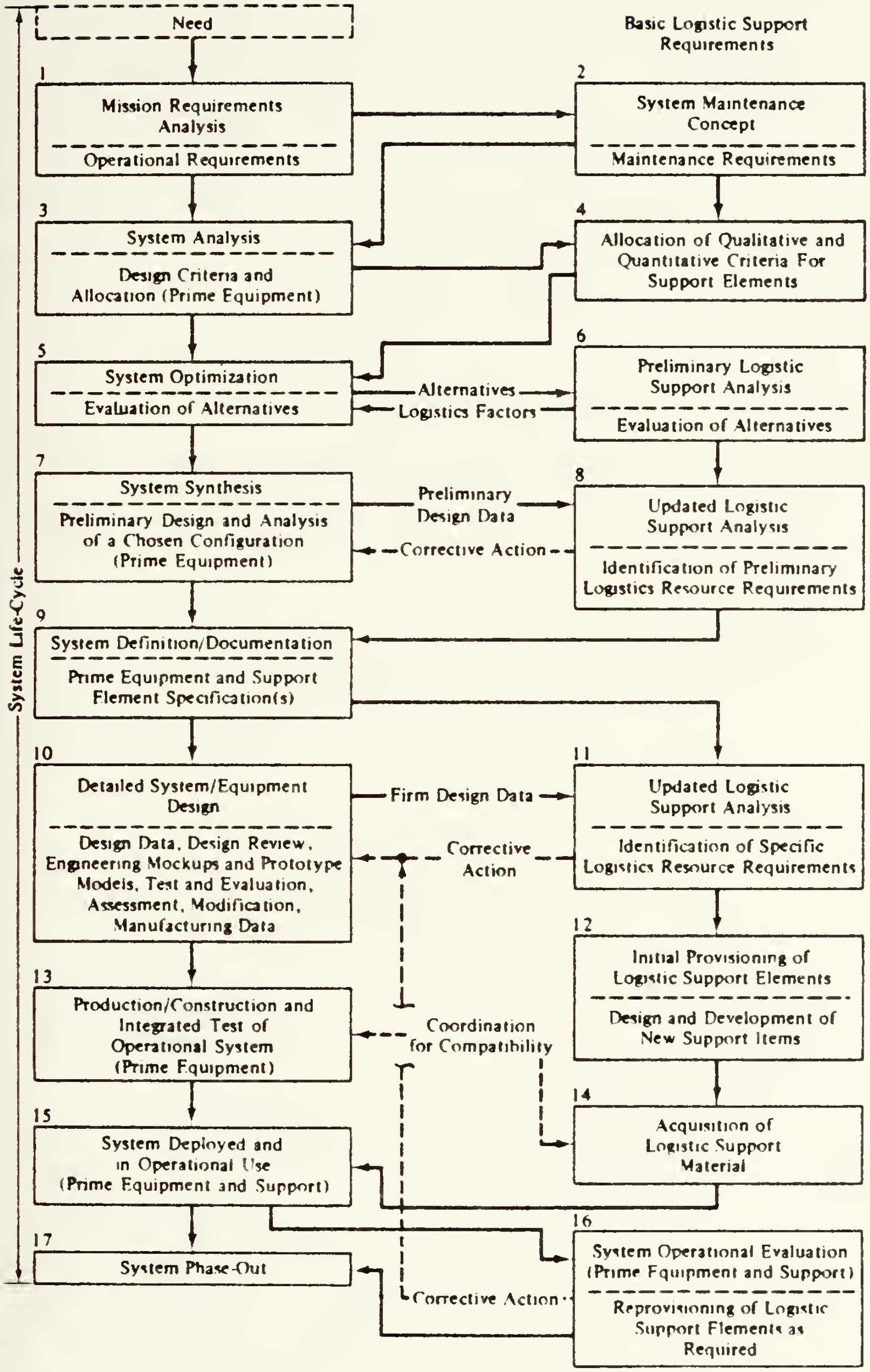


Figure 1-1. System development process.

Figure A-5. System Life Cycle and Logistics Interfaces [Ref. 2]

APPENDIX B

COST-EFFECTIVENESS

B.1. INTRODUCTION

Any system is required to be cost-effective, which means it must fulfill needs within constraints specified by economic, operational, and support requirements, and do so as economically as possible. Thus, cost-effectiveness relates to the measure of a system in terms of system effectiveness (level of mission fulfillment), and total life cycle cost (a monetary value).

The cost-effectiveness methodology and approach is based upon an economic evaluation of engineered systems, assuming that each system has a certain worth in terms of the missions for which it has been designed. Prime elements of the concept are illustrated in Figure B-1.

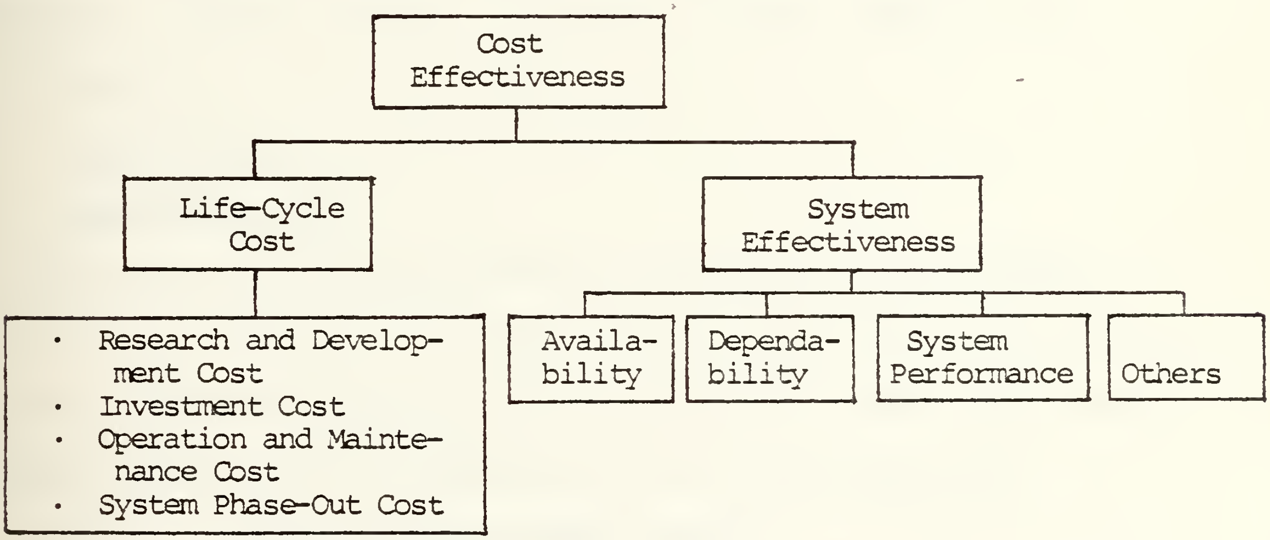


Figure B-1. Prime Cost-Effectiveness Elements [Ref. 2]

B.2. SYSTEM EFFECTIVENESS

One of the major facets of cost-effectiveness is the mission fulfillment ability of a system. System effectiveness is basically concerned with a system's ability to perform successfully a defined mission in the intended environment. To express this in quantitative terms, a number of measures have been derived. They are widely used as a prediction tool for system-effectiveness during the formulation of system design, and for evaluations during the Use Period.

System effectiveness is primarily concerned with three major concepts [Ref. 2]:

a) System Performance (Design Adequacy, Capability, Utilization)--the probability that the system will perform its mission when operating within designed specifications (capacity, range, altitude, accuracy, weight, shock, and vibrations).

b) Availability.

c) Dependability.

A combination of the above measures represents the system-effectiveness aspect of the cost-effectiveness approach. Various logisitc elements have a significant impact upon these measures, especially on availability and dependability.

B.2.1. System-Effectiveness Models

An early attempt to develop concepts of system-effectiveness was done by ARINC Research Corporation. Their definition of system-effectiveness is: "the probability

that the system can successfully meet an operational demand within a given time, when operated under specified conditions." The three components emphasized in this definition are mission reliability, operational readiness, and design adequacy (Figure B-2), which are defined as follows [Ref. 7]:

a) Mission Reliability (MR)--the probability that, under stated conditions, the system will operate in the mode for which it was designed for the duration of the mission, given that it was operating in this mode at the beginning of the mission.

b) Operational Readiness (OR)--the probability that, at any point in time, the system is either operating satisfactorily or ready to be placed in operation on demand, when used under stated conditions (including stated allowable warning time. Thus, the basis for its computation is total calendar time).

c) Design Adequacy (DA)--the probability that the system will successfully accomplish its mission, given that the system is operating within design specifications.

The model distinguishes between the terms "Operational Readiness" and "Availability", which are often used as synonyms. The latter was defined as "the probability that the system is operating satisfactorily at any point in time when used under stated conditions, where the total time considered includes operating time, active repair time, administrative time, and logistic time." Using these definitions, System Effectiveness (SE) is expressed as a product of the

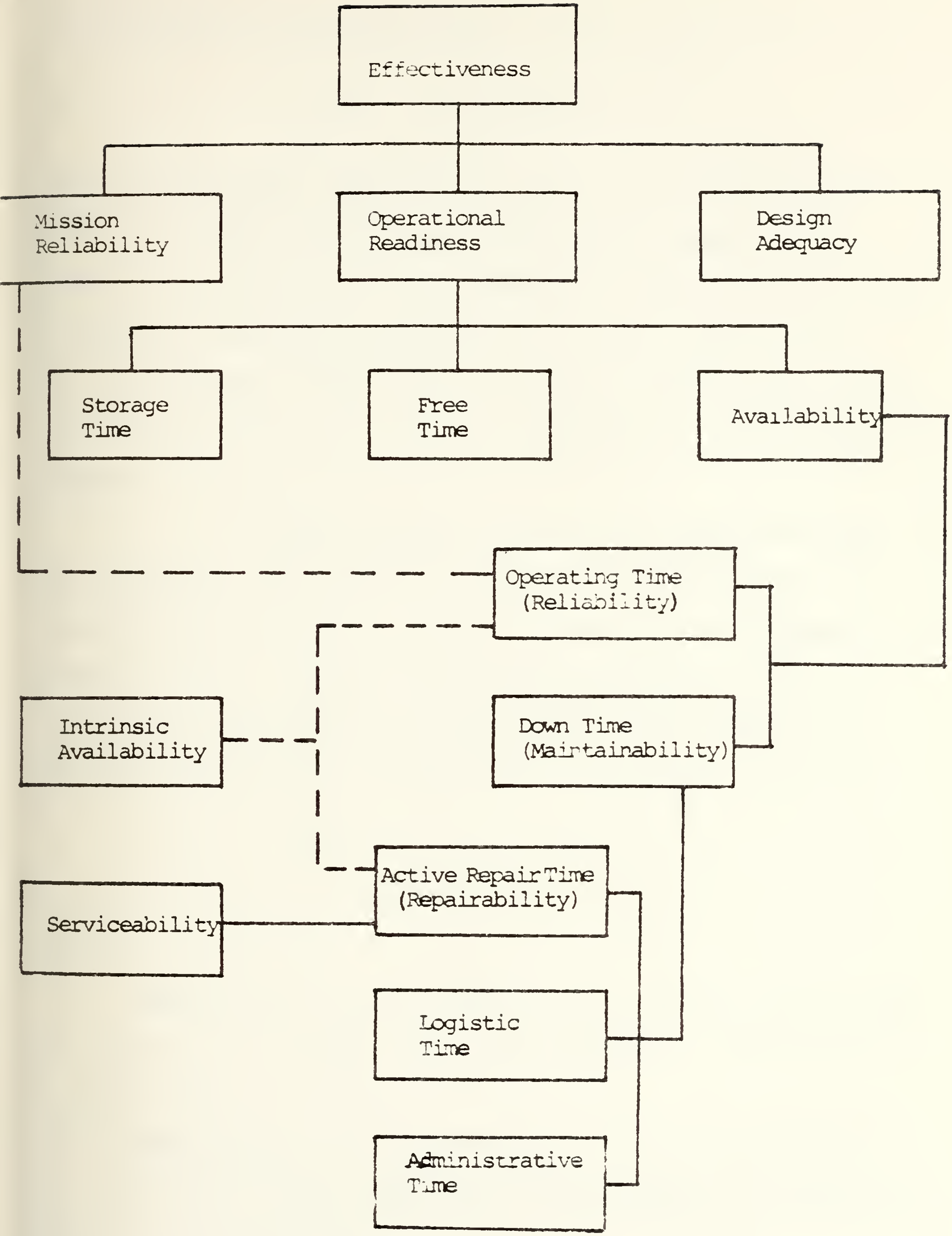


Figure B-2. Concepts Associated with System Effectiveness

three probabilities OR, MR, DA:

$$SE = OR \times MR \times DA$$

which are defined, respectively, as: (1) the probability that the system is operating satisfactorily/ready to be placed in operation; (2) the probability that the system will continue to operate satisfactorily for the mission time; (3) the probability that the system will successfully accomplish its mission, given that it is operating within design limits.

Another system-effectiveness model developed by the US Air Force, defines system-effectiveness as: "a measure of the extent to which a system may be expected to achieve a set of specific mission requirements, and is a function of availability, dependability, and capability." System effectiveness is expressed by the formula [Ref.21]:

$$SE = A \times D \times C$$

where,

a) Availability (A)--a measure of the system condition at the start of the mission, when the mission is called for at a random point in time.

b) Dependability (D)--a measure of the system condition at one or more points during the performance of the mission, given the availability.

c) Capability (C)--a measure of the ability of the system to achieve the mission objectives, given the dependability.

When comparing the ARINC model to the WSEIAC model, quite a similarity may be noted.

B.2.2. Operational Readiness, Dependability, and Availability. The terms Operational Readiness, Dependability and Availability have similar connotations. It is, important, therefore, to discuss each one of them in more detail, to achieve a better understanding.

B.2.2.1. Operational Readiness includes total calendar time as a basis for its computation (free time, storage time, operating time, active repair time, logistic time, and administrative time). The most adequate definition of it seems to be the one suggested by ARINC Research Corporation.

B.2.2.2. Dependability. The preferred approach for expressing Dependability seems to be the one developed for the US Navy, which takes into consideration the fact that, in many instances, a failure occurring during an operating period t_1 may be acceptable if it can be corrected in a specified time $\leq t_2$, and the system continues to complete its mission [Ref. 22]:

$$D = Rm + (1 - Rm)Mo$$

where

D = System Dependability--the probability that the mission will be successfully completed within the mission time t_1, given the down-time per failure $\leq t_2$ will not affect the overall mission.

Rm = Mission Reliability--the probability that the system will operate without failure for t_1. ($R_m = e^{-\tau/MTBF}$ for a constant failure rate, and a mission duration of τ).

Mo = Operational Maintainability--the probability that the failure, when it occurs, will be repaired with a time $\leq t_2$.

This concept applies particularly for systems with long mission times, in which system failures do not necessarily cause mission aborts.

B.2.2.3. Availability, which is the probability that the system will operate satisfactorily at any point in time when used under stated conditions, may be defined as a ratio of the uptime (the total time the system is capable of performing its function) to the uptime plus down-time (total time where there is demand for the system). The following three kinds of availability have been defined [Ref. 6]:

a) Inherent (Intrinsic) Availability--a measure of the intrinsic design variables only, controllable by the system designer.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where:

A_i = Inherent Availability;

MTBF = Mean-Time-Between-Failures;

MTTR = Mean-Time-To-Repair (Restore).

b) Achieved Availability--a measure which includes preventive maintenance in an ideal support environment.

$$A_a = \frac{MTBM}{MTBM + MADT}$$

where:

A_a = Achieved Availability;

MTBM = Mean-Time-Between-Maintenance;

MADT = Mean-Active-Down-Time

= Mean Corrective Maintenance Time + Mean Preventive Maintenance Time.

c) Operational Availability--An extension of the term Aa to the actual operating environment, including delay times.

$$A_o = \frac{MTBM}{MTBM + MDT}$$

where:

A_o = Operational Availability;

MDT = Mean-Down-Time

= MADT + Logistic Time + Administrative Time.

Availability is a relatively simple concept. Therefore, it has received the largest attention in system -effectivness measures.

B.2.2.3.1. Availability Breakdown. System Availability concerns itself with two major issues:

a. Reliability (Operating Time)

b. Maintainability (Down Time).

B.2.2.3.1.1. Reliability Considerations. Reliability may be viewed as a system's ability to operate at or above prescribed thresholds for the duration of an assigned mission in an operational environment. In probabilistic terms it may be defined as [Ref. 22]: "the probability that a system will perform its intended function for a specified interval under stated conditions." Being a systems engineering discipline, reliability encompasses different issues of material science, statistics, design, physics of failure, product assurance, and management.

Reliability features should be incorporated in the system design by means of high reliability components, use of redundancy, development testing, stress theory, and failure analysis.

A basic concept in reliability is the Bathtub Curve, which represents the instantaneous failure rate. It consists of three regions, called "infant mortality region," "constant failure rate region," and "wearout region." Referring to the middle portion of the curve, test and field data covering a variety of systems have indicated that in electronic systems, the failure rate (λ) can often be assumed to be relatively constant. It allows the implementation of the Poisson (random)

distribution arrival of failures, where the exponential distribution fits the time-to-failure random variable. The exponential law may be used, thus,

$$R(t) = e^{-\lambda t} = e^{-t/MTBF}$$

where:

$R(t)$ = systems reliability at time t;

$\lambda = \frac{1}{MTBF}$ = failure rate

λ is a significant factor in determining the frequency of corrective maintenance.

B.2.2.3.1.2. Maintainability Considerations. Maintainability is a characteristic of system design which determines a system's ability to be restored to or retained in an effective usable condition. Together with reliability, maintainability determines the system's operational readiness, and contributes to the system effectiveness concept [Ref. 23].

Maintainability engineering concerns itself with various disciplines, including human factors, maintenance technician skill levels, safety, and system attributes such as accessibility, test and checkout philosophy, test equipment, controls, and displays. All these disciplines are included to ensure effective and economical maintenance within prescribed operational readiness requirements.

Being a part of systems engineering, maintainability is considered in terms of the system life cycle, and is related to system trade-offs, and life cycle costs. Resources associated with maintainability include test and support equipment, spares and repair-parts, maintenance personnel, training equipment, maintenance facilities, and maintenance instructions and data. The extent to which these resources are utilized depends upon specified maintainability features which are designed into the system.

Affecting heavily the annual military budget (up to one third is spent on maintenance), maintainability issues should be deeply considered during all system development phases. Thus, during the Conceptual and Definition Phases, moderate investments in maintainability and support design requirements may lead to substantial savings in the Use Period, while ignoring them may cause an excessive maintenance and support expenditure [Ref. 1].

A system to which maintainability engineering has been properly applied can be expected to have lower downtimes (high availability), quicker restored, and retained longer in an operational state. Therefore, the purpose of maintainability is to provide maximum operational readiness by enabling quick maintenance performance (consistent with all other system requirements) with given support resources used.

To achieve this purpose, a variety of techniques for prediction, demonstration and evaluation have been developed, using statistical measures, such as MTTR, median and maximum repair time, maintenance man-hours per unit, etc.

A cost-effective system depends upon the proper balance between reliability and maintainability. The latter interacts with safety requirements (access, protection from environmental hazards), configuration (location of test points, tools, connectors, handles), and costs (cost of maintenance and support versus maintainability design cost).

During recent years, experience has shown substantial deviations between maintainability predictions and demonstrations, and actual field data obtained from system use in its operational environment [Ref. 9]. Actual repair-times have been proved to be several time longer than the initial predictions and demonstrations. Because they affect life support cost significantly, this experience should be used in system procurement decisions.

B.3. LIFE CYCLE COST

The second, and a very important part of cost-effectiveness is Life Cycle Cost (LCC). It is defined as "the sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred, or estimated to be incurred, in the design, development, production, operation, maintenance and support of a major system over its anticipated useful life span" [Ref. 24].

Cost elements to be included in a given LCC must be defined for each case separately, but despite that, the gross approach towards LCC breakdown is that illustrated in Figure B-3. The total cost of a system includes all

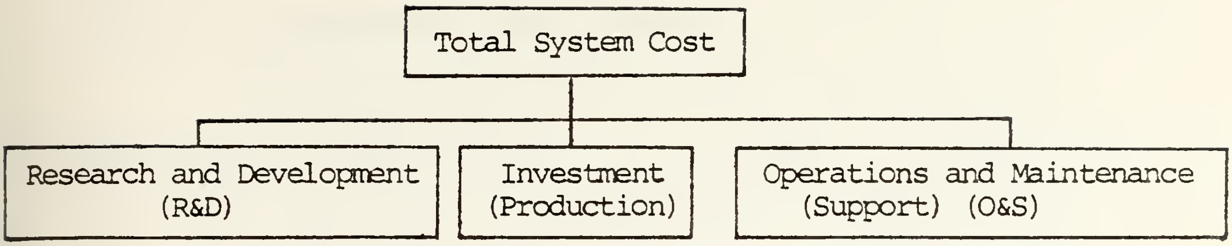


Figure B-3. General LCC Breakdown

expenses for R&D, production, modification, transportation, facilities, support, disposal, and any other ownership costs less salvage revenues at the end of its lifetime.

Use of the LCC concept is a result of smaller budgets dedicated for the DOD by the U.S. Federal Government during recent years. These tighter budgets caused the use of more "scientific" approaches in budget planning, after realizing that procurement costs represent only a part of the total life cycle costs, and are, therefore, an inadequate measure to be used for planning purposes and in procurement decision processes. Analysis of DOD budgets confirmed that operation and support costs compose 40%-60% of the DOD budget as a whole, and caused a greater interest in this area. As a result, the main decision factor in selection of new systems has shifted from purchasing costs to LCC [Ref. 1].

The main motivation behind LCC analysis is the possibility of saving money on O&S costs by increasing the expenditure during the R&D phase. It enables the analyst to provide the management with an overall quantitative picture of the system life cycle, and contributes to various decisions reached during the life-cycle phases.

B.3.1. Life-Cycle Cost Drivers

The LCC effort concentrates on the search for those system characteristics that result in large cost portions, realizing that it is impossible to devote the same effort to each of the cost elements. These significant costs, when isolated, are used to reduce the LCC of the system by applying trade-off techniques, modification of policies, and design changes.

Although cost drivers are peculiar to each system, some of them can be found frequently, such as stockage levels, level of repair, downtime, training, manpower, and facilities. Concentration upon those elements makes an efficient LCC program possible.

B.3.2. Inflation and Discounting

Inflation and Discounting can both be used to modify future costs to present costs. Various LCC estimates can be presented either in "current dollars" or in "constant dollars", with the first preferred.

The effect of inflation and discounting can be combined into an adjustment factor for each year's cost, as follows [Ref. 1]:

$$AF = \left\{\frac{1 + i}{1 + d}\right\}^n$$

where:

AF = adjustment factor

i = average inflation rate/yr

d = average discount rate/yr. (usually $d = 0.1$)

n = number of years

Usually, military organizations do not have a predictable stream of revenues. Therefore, the present value method, used in the private sector, can be modified into a discounting method. Other capital investment financial analysis methods (such as return on investment or pay-back period) are not recommended for use by military organizations, which often tend to ignore even the discounting method, as well as inflation (the latter is compensated through annual budgets).

B.3.3. Life-Cycle-Cost Breakdown

A Life Cycle Cost Breakdown Structure (LCCBS) is an ordered breakdown of the components of LCC, which represent an accounting model for LCC estimates. Although a standard LCCBS does not exist, many common elements are included in a lot of them. The first breakdown level includes usually three categories: Research and Development, Production (Investment), and Operations and Support (or Maintenance) costs. A possible LCCBS is illustrated in Figure B-4.

B.3.3.1. Research and Development Costs. Research and Development (R&D) costs include all the expenses necessary to produce a set of engineering drawings and specifications for release for manufacturing. They cover the conceptual, definition, and the full-scale development phases. Systems engineering studies, design, development, testing, prototype fabrication, O&S planning, and manufacturing planning costs are included in this category, in addition to customer

Development Cost
- Concept Formulation Cost
- Validation Cost
- Full-Scale Development Cost
  - Program Management
  - Engineering
  - Fabrication
  - Contractor Dev. Tests
  - Test and Eval. Support
  - Data
  - Producibility Eng. & Planning

Investment Cost
- Non-Recurring Investment Cost
  - Program Management
  - Producibility Eng. & Planning
  - Initial Production Facilities
  - Initial Spares and Repair Parts
  - Common Support Equipment
  - Peculiar Support Equipment
  - Data
  - Initial Training
  - Technical Support
- Recurring Investment Cost
  - Manufacturing
  - Production Material
  - Sustaining Engineering
  - Quality Control and Inspection
  - Packaging and Transportation
  - Operational Site Activation

Operations and Support Cost
- Operations Cost
  - Electric Power
  - Consumables
  - Operational Personnel
  - Lease
- Support Cost
  - Maintenance Personnel
  - Maintenance Facilities
  - Support Equipment Maintenance
  - Contractor Services
  - Inventory Administration
  - Inventory Holding
  - Replenishment Spares
  - Repair Material
  - Transportation and Packaging
  - Supply Facilities

Figure B-4. Life Cycle Cost Structure [Ref. 12]

testing costs, and qualification test costs. R&D costs are divided into non-recurring and recurring costs (one-time costs vs. costs that occur with each unit produced). A typical R&D cost breakdown is illustrated in Figure B-5.

B.3.3.2. Investment Costs. Investment costs occur during the production phase. The non-recurring costs of this category include tooling, support and test equipment, manufacturing planning, new facilities, training and recruitment, while the recurring costs include manufacturing labor, material, inspection, and support equipment maintenance. These costs are charged directly to a particular part/equipment produced, while other costs, such as building maintenance, supervision, clerical personnel, and accounting costs are accumulated and allocated to each part/equipment as overhead.

A typical investment cost breakdown is illustrated in Figure B-6.

B.3.3.3. Operation and Support Costs. O&S costs account for the largest part of LCC during the Use Period of the system. Operating costs are the incurred costs, and include operating personnel, energy, and operating support costs. Support costs include the various costs for maintenance, provisioning, support equipment, transportation, training, documentation, site preparation, installation and security.

Being the largest part of LCC, O&S costs require a detailed examination. It is obvious

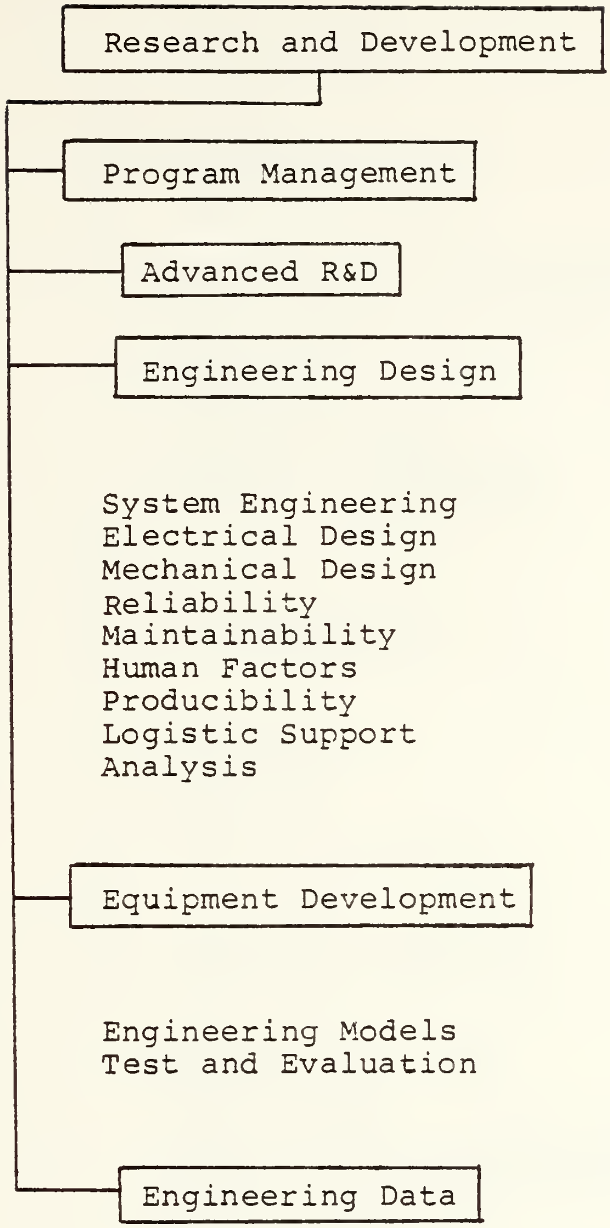


Figure B-5. R&D Cost Breakdown [Ref. 2]

Investment

Manufacturing

Manufacturing Engineering
Tools and Test Equipment
Fabrication
Assembly
Inspection and Test
Quality Control
Material (Inventory)
Packing and Shipping

Construction

Fabrication
Material
Utilities
Capital Equipment

Logistic Support

Program Management
Provisioning
Initial Spare/Repair Parts
Initial Inventory Management
Preparation of Technical Data
Initial Training
Test and Support Equipment
First Destination
  Transportation

Figure B-6. Investment Cost Breakdown [Ref. 2].

that these costs depend directly on how much the system is used. For military systems these costs tend to increase dramatically during wartime, but because wars are difficult to predict, O&S cost estimates are based on peacetime operations. A typical breakdown of O&S costs is illustrated in Figure B-7.

B.3.3.3.1. Operating Costs are costs associated with the use of the equipment/system. One of their major elements is the operating personnel cost, which includes expenditure on each operating person needed, such as salaries, cost of training, non-productive time, recruitment cost, and retirement cost. Usually, operating personnel costs will not include overhead costs (headquarters and staff office).

Another important cost element included in Operating Costs is the energy cost element (petroleum, oil, electrical, and nuclear power), which may account for a significant part of the LCC. Diverse consumables used by various weapon systems (such as ammunition, bombs, and rockets), in addition to materials and supplies for personnel (such as food, uniforms, tools, and medicines) account for a large portion of operating costs. External support system costs required for operating military systems (aircraft carriers, command and control networks, air defense systems) are often allocated to each system under consideration.

Operations and Maintenance

- Operations
  - Personnel
  - Replenishment Training
  - Operational Facilities
  - Handling Equipment
- Maintenance
  - Maintenance Personnel and Support
    - Organizational
    - Intermediate
    - Depot
  - Spare/Repair Parts
    - Organizational
    - Intermediate
    - Depot
  - Test and Support Equipment Maintenance
  - Transportation and Handling
  - Maintenance Replenishment Training
  - Maintenance Facilities
  - Technical Data Changes

Figure B-7. Operation and Support Cost Breakdown [Ref. 2]

B.3.3.3.2. Support Costs. Support costs account for the largest part of O&S spendings and are mainly generated by maintenance requirements. These costs can be derived from the Integrated Logistic Support (ILS) planning, which integrates the maintenance plan, the support and test equipment plan, supply support, transportation and handling, technical data, facilities, personnel and training, logistic support funds funding, and logistic support management information.

B.3.3.3.2.1. Maintenance Costs arise from preventive and corrective maintenance activities performed. These costs are incorporated in all maintenance levels (operational level, intermediate level, and depot level). It is important to recall that sometimes these cost estimates run as low as one-eighth of the actual costs obtained during initial deployment of new systems, mainly because of deviations in maintainability measure estimates [Ref. 1]. Software maintenance costs (revisions and correction of computer programming software) may be added to the total maintenance costs calculated in the LCC.

B.3.3.3.2.2. Inventory Costs include two cost categories:

a. initial and replenishment spares and repair-parts costs;

b. supply management costs.

The first category contains expenses on initial procurement of spares and repair parts, which allow the new systems to operate for an initial period of time on a defined availability

level and replenishment inventories purchased to maintain the desired availability level for the Use Period.

The second category accounts for administrative cost of entering a new item into the inventory system, and the cost of retaining it in the supply system.

B.3.3.3.2.3. Support Equipment Costs arise from procurement and maintenance of test equipment, tools, calibration equipment, and transportation and handling. These costs are usually categoriezed as peculiar or common, and according to this distinction apportioned to the systems purchased.

B.3.3.3.2.4. Training Costs include training equipment, facilities, and service costs (simulators, mock-ups, books, manuals, special training aids, and cost of instructors and students).

B.3.3.3.2.5. Technical Documentation Costs include costs of technical manuals and logistic data required for operation and maintenance of the equipment.

B.3.3.3.2.6. Transportation and Handling Costs include costs of packaging, handling, and transportation of spares, repair parts and material between maintenance levels and supply points, in support of maintenance activities.

B.3.3.4. Miscellaneous Costs are sometimes considered as a fourth cost category of LCC (auxiliary costs and phase-out costs). A major cost element of this

category regards new or modified constructions. It may include facilities (for operations, maintenance, supply, and training), site preparation (roads, bridges, and foundations), site installation (plumbing, wiring, pipelines, air-conditioning, and communications), and security requirements (fences, gates, bunkers, and detection devices). Of these, the most important for LCC considerations is construction of new elements, such as silos, launch pads, test range modifications, and weapon-system facilities. During the evaluation process of various feasible alternatives, such issues as rental vs. construction costs should not be ignored, as well.

Another cost element to be considered is the Disposal Cost. The necessary activities for destroying missile silos, bomb shelters, concrete structures, and nuclear devices are complicated and often very expensive. On the other hand, revenues may be gained at the end of the life-cycle. Portions of obsolete systems can usually be sold, sometimes even whole constructions (such as ships or airplanes). With regard to military systems, the Foreign Military Sales issue should be incorporated into the LCC calculations, when a possibility of sales to other countries exists.

APPENDIX C

THE OPUS-VII MODEL

C.1. INTRODUCTION

The OPUS procedure [Ref. 18] was developed by SYSTECON AB, Stockholm, Sweden. The original modelwas designed in 1970 as a computer-based aid for initial provisioning of spares. New requirements and experience from more than 100 different project applications have led to improvements, making the current version of OPUS-VII a highly efficient and useful tool with regard to the following types of problems:

-- Initial procurement of spares and the allocation of them within a support organization.

-- Reallocation of a given assortment of spares.

-- Replenishment procurement of spares.

-- Reallocation of a given assortment and initial procurement of new types of spares.

-- Cost-effectiveness evaluation of alternative maintenance and supply support concepts, and alternative system configurations.

Depending upon the type of problem, one or more of the following Measures of Effectiveness (MOE) can be chosen:

-- System operational availability.

-- Probability of successful mission performance.

-- Risk of shortage when a spare is being demanded.

-- Mean waiting time for a spare.

As for other computer models, the quality of the input data determines the quality of the output data. For a new

system, input data has to be gathered from several different sources, including the manufacturer, and some uncertainty may be involved. To cope with this problem, OPUS-VII has the ability to perform sensitivity analysis on the most important variables. Input data is needed about the deployment and operation of the equipment, the structure of the maintenance and supply support organization, and the material structure of the system.

Combinations of the different MOE's and problem types will result in a large amount of information. In general, the output contains the following:

-- Graphs, illustrating how the MOE chosen depends on the level of investment.

-- Tables for different levels of investment, describing for each type of spare the number to be purchased and how these items are best assigned to the different stocks within the organization.

-- Tables showing how the total initial investment costs of spares are distributed among the different levels of the maintenance organization, and with regard to the assortment of spares chosen.

-- The overall cost-effectiveness curve for the problem.

OPUS-VII has the capability of accepting data for a fairly complex system. A maximum of 500 spares can be handled. If the problem is larger, it must be broken down into subproblems which are handled individually. The results of the subproblems are combined by a special computer program, OPUS-VII W,

which performs a marginal cost analysis, and determines the overall cost-effectiveness curve.

C.2. INPUT DATA REQUIREMENTS

C.2.1. System Data

OPUS-VII was designed to handle systems with two indenture levels, Line Replaceable Units (LRU's) and Shop Replaceable Units (SRU's) (Figure C-1.). Repair parts can be included in the analysis by treating each LRU as a system, and its SRU as an LRU; in this analysis the repair parts are regarded as SRU's.

Recognizing that a specific LRU or SRU may be common to several different system types, the model has the capability to handle more than one system in a single computer run. This requires that the input-data contain the following:

a) System Data:

-- The number of system types.

-- For each system type:

- System MTBF
- The number of different LRU's
- The number of each LRU type.

b) LRU Data:

-- Unit cost.

-- LRU MTBF for each item.

-- The number of different SRU's.

-- The number of each SRU type.

c) SRU Data:

-- Unit cost.

-- SRU MTBF for each item

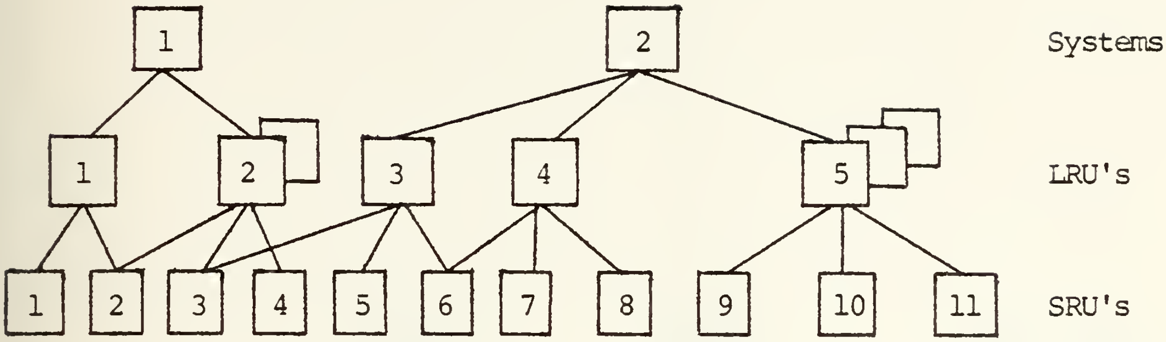


Figure C-1. An Example of System Breakdown

C.2.2. Data for the Support Organization

The maintenance and the supply support organizations must be built up in a hierarchical way. No flow of spares between stations at the same level (echelon) of the organization can take place. (This requirement can be softened by use of "dummy stations", with a turn around time of zero.) The model operates with three types of stations in the support organization (Figure C-2):

a) End Support Station (ESS), corresponds to depot level, and may include stockage facilities for the depot.

b) Support Station (SS), corresponds to intermediate or system level of a maintenance organization, and/or to a stockage facility.

c) Demand Generating Station (DGS), corresponds to operational systems.

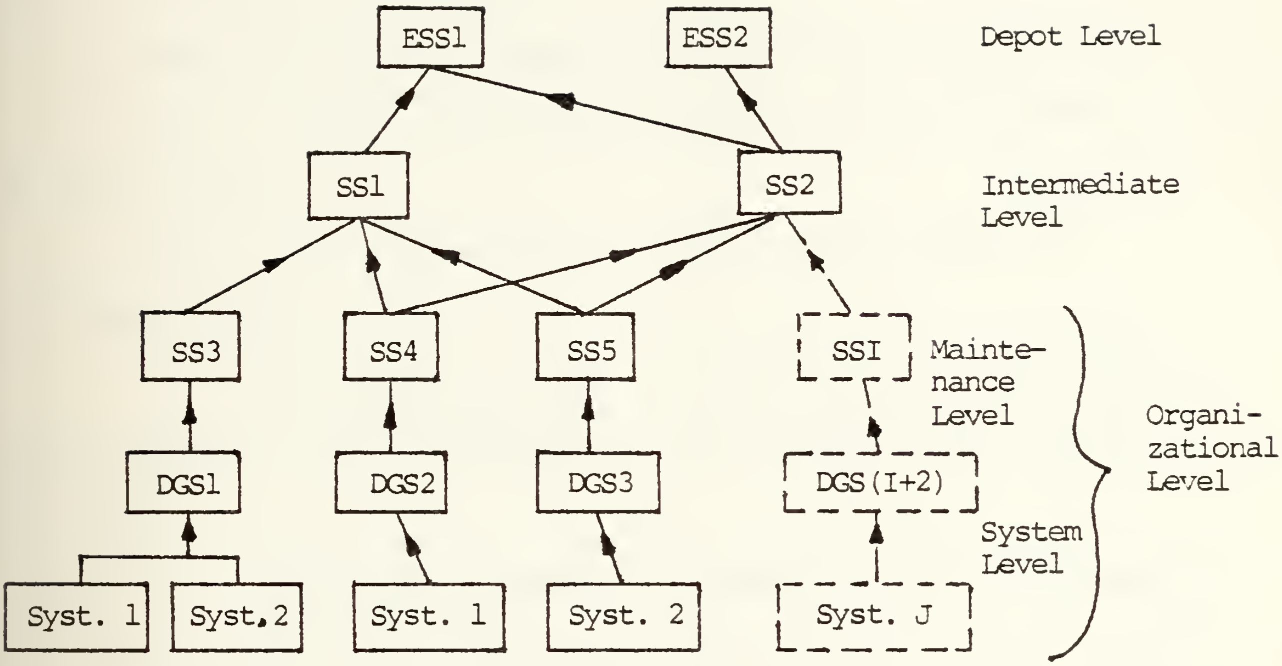


Figure C-2. Possible Support Organization; An Example

Each DGS must be supported by one and only one SS (the system maintenance level). This SS must be supported by one or more SS (intermediate level), or by an ESS. The requirements are not real restrictions. By use of fictitious SS, it is possible to model almost any support organization.

The following types of input-data must be specified for each SS:

-- A reference to one or several stations to which propagated demands are addressed.

-- Identification of items which may be kept in stock.

-- Time to repair every item of each system, if repaired at this station.

-- Time to get a spare from a superior SS, given no shortage exists.

An ESS is similar to an SS with the exception that a demand is not propagated to any higher level support station.

The time to satisfy a demand at an SS depends on the stock level, the demand rate, and the turn around time for support, which is composed of a fixed time, including logistic time, transportation time, etc., and a variable time, representing the expected waiting time for the type of item being demanded.

C.3. ASSUMPTIONS USED IN THE COMPUTATIONS

The development of the OPUS-VII algorithms has been based on the following assumptions:

-- The demands are Poisson distributed.

-- Mean values of turnaround times are known.

-- A failure of one item is statistically independent of those that occur for any other type of item.

-- Repair times are statistically independent.

-- No queues are assumed in the repair organization.

-- The system has been in operational use for a period of time, long enough that all transients have faded out.

C.4. MATHEMATICAL DESCRIPTION OF THE MODEL

The key variables describing the steady-state condition at a certain position of the support organization are stock level, demand rate, turn-around time, unit cost of items stocked, and the MOE to be used.

The turn-around times are computed using a procedure very much like the one used for calculation of system mean down-time ($\overline{\text{MDT}}$) per failure, described in Section 3.2. All appropriate time elements of the repair cycle must be included in the input data.

C.4.1. Computation of Measures of Effectiveness

Computations of all MOEs are based upon a probabilistic approach.

C.4.1.1. Expected Waiting Time (EWT) and the Expected Number of Backorders

EWT is the average time needed to satisfy a demand. It is computed for each type of spare part and for all portions of the support organization. The formula for EWT is developed under the following assumptions:

-- A demand can be satisfied immediately if fewer than N (N is the number of this spare part procured for stockage at this position) demands have occurred during a period of time equal to the turn-around time (TAT) for this position, EWT equals zero.

-- Spare parts are equally spaced in time in the repair cycle. For (N+x) demands during TAT the time space will be $\frac{TAT}{N+x}$.

The first x items finishing the repair cycle will not be available for the $(N+x)^{th}$ demand, for which EWT will be $x \times \frac{TAT}{N+x}$.

The formula for EWT is

$$EWT = P\{f < N\} \times 0 + \sum_{x=0}^{\infty} P\{f = N+x\} \times TAT \times \frac{x}{N+x}$$

$$= \sum_{x=0}^{\infty} P\{f = N+x\} \times TAT \times \frac{x}{N+x}$$

where f is the number of demands, P{f} is the Poisson probability of f demands, and TAT is the turn-around time for this spare part if sent to higher echelon.

The expected number of backorders (ENB) at each position of the organization is computed for each type of spare parts as

$$ENB = D \times EWT$$

where D is the demand rate.

C.4.1.2. System Availability

Based upon the values of EWT it is possible to compute the average downtime per failure (EDT), and the system availability (A). The formula used by OPUS is:

$$A = \frac{1}{1 + D \times EDT}$$

The demand rate is $D = \frac{1}{MTBF}$ and the formula may be rewritten as:

$$A = \frac{MTBF}{MTBF + EDT}$$

which is the formula used in Section 3.2.

The expected number of nonavailable systems (NORS) is found as

$$NORS = N \times (1 - A)$$

where N is the total number of systems.

C.4.1.3. The Probability of at Least One Backorder (PALOB)

This measure is found as one minus the probability of zero backorders, or

$$PALOB = 1 - P\{f \leq N\} = P\{f > N\}$$

where P{f} is the Poisson probability of f failures during the turn-around time (TAT), and N is the number of that spare part

procured for the stock. This gives

$$PALOB = \sum_{x=1}^{\infty} [e^{-(TAT \times D)} \times (TAT \times D)^{(N+x)}/(N+x)!]$$

C.4.1.4. <u>The Probability of Shortage Given a Demand (PSGD)</u>

PSGD is defined in the OPUS manual as: "The probability that a given demand can not be satisfied within a certain amount of time (T) due to shortage in stock." The value of T may be specified as an input to the program or, a built-in procedure will decide this value. A shortage in stock lasting less than T time units will be left out of account. For values of T greater than TAT, the probability of a shortage is set to zero. For T < TAT, PSGD is:

$$PSGD = \sum_{x=0}^{\infty} [e^{-(TAT \times D)} \times (TAT \times D)^{(N^*+x)}/(N^*+x)!]$$

where N* is the integer part of

$$N \times T/(TAT-T)$$

and other variables are as described above (C.4.1.3.).

C.4.1.5. <u>The Probability of Successful Mission (PSM)</u>

This measure is relevant when the system must operate for a period of time without connection to the rest of the support organization (e.g., on board a ship), and only LRU's are allowed to be stocked at the system's level.

Two new variables are introduced, MT is the mission time and TBM is the time between missions.

Taking into consideration that a demand may be satisfied during TBM, the probability that no unsatisfied demand will occur (POLLD) during MT is computed for each LRU, provided that the mission started with a given number of the spare part in stock.

The weighted probability of successful mission performance is then given by the formula:

$$PSM = \prod_{i=1}^{n} POLLD(i)^{M(i)}$$

where n is the number of different LRU's and M(i) is the quantity of LRU(i).

C.4. THE OPTIMIZATION ALGORITHM

The cost-effective allocation of spare parts is in principle performed according to the following procedure:

a) The only procurement allowed is of LRU's for the highest level (Depot) of the support organization. The LRU giving the best marginal return on investment (improvement of MOE per $) is procured first. The LRU with the highest marginal return on investment, given previous procurements, is procured next. This procedure continues until a specified level of investment is reached, or the specified value of the MOE is obtained. A number of points of a "Cost-effectiveness curve number 1" is found (See Figure C-3).

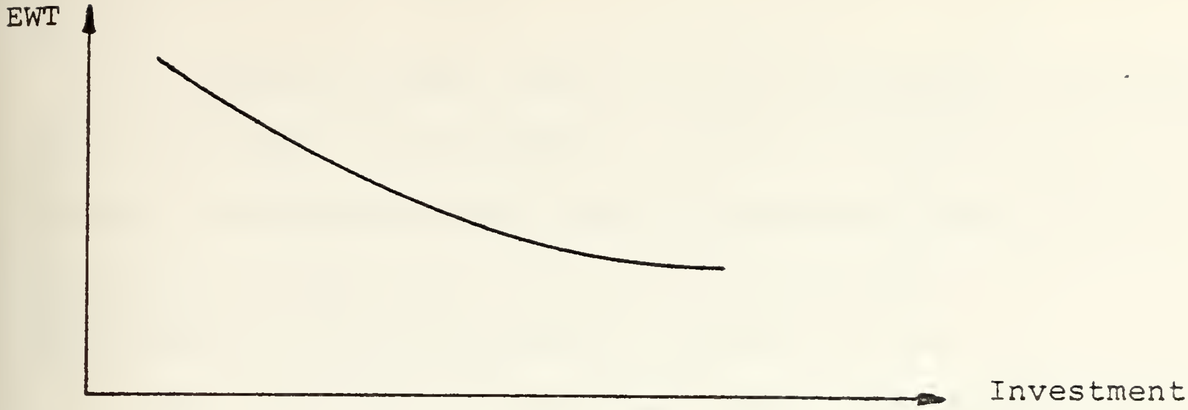


Figure C-3. C-E Curve Number 1

b) Allow for procurement of SRU's for the highest level and LRU's for the next highest level (normally intermediate level or a stockage facility) of the organization. Select a number of points (maximum fifty) of "C-E curve number 1." For each of these points, compute the marginal return on investment for each spare part, and procure the one with highest return per $ given previous procurements. Find the next spare part to procure etc. A set of CE curves is obtained (see Figure C-4), the envelope of which is "C-E curve number 2."

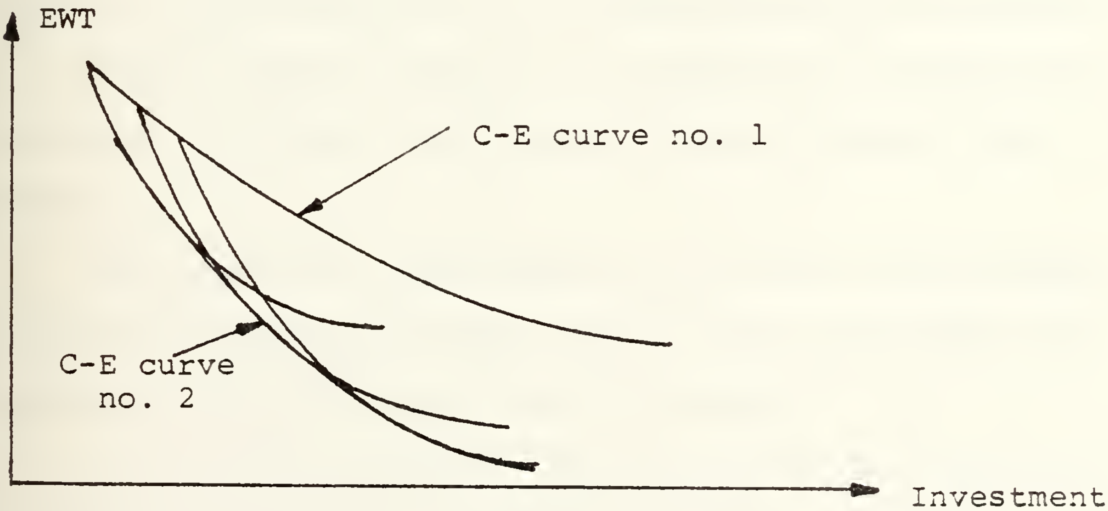


Figure C-4. C-E Curve Number 2

c) Include the next lower level of the support organization and repeat the procedure, item (b). Continue until LRU's for the maintenance level directly supporting the system is included, and the final C-E curve is obtained.

The results of the optimization procedure are:

-- For each level of investment, an optimized value of the MOE.

-- For each level of investment, the optimal assortment of spare parts.

-- For each assortment of spares, the optimal stockage policy.

C.5. LIMITATIONS

A maximum of 500 different types of LRU's and SRU's can be handled by OPUS-VII. The product of the number of different stock points and the number of different types of spare parts can not exceed 1500. Larger problems must be divided into subproblems, each subproblem is then analyzed by OPUS-VII. The results of the subproblems may be combined by a special computer program, the OPUS-VII W, which will determine the overall cost-effectiveness curve for the problem.

The assumption that demands are Poisson distributed, is valid for electronic systems, but is less practicable for mechanical and some other types of systems.

It is assumed that no queues exist in the repair cycle. For some spare parts it is normal to batch a number of items before repair is undertaken. If so, OPUS-VII will overestimate the MOE.

APPENDIX D

LEVEL OF REPAIR MODEL (LOR MOD III, AIR)

D.1. INTRODUCTION

Level of Repair (LOR) models are used to determine the Life Support Cost (LSC) policy during the operating and support phase of the life cycle. These models, therefore, omit acquisition costs. Four models known as "Military Standard 1390-B(NAVY) LOR" models exist. One of these, the "Naval Air Systems Command Equipments" (AIR) model has been used for this thesis.

The AIR computer program is complex and written in SIMSCRIPT. This could be a drawback if the user does not have a SIMSCRIPT compiler since the model is meant to be used by the manufacturer in the early phases of the system life cycle, as well as by the user later on.

LOR analyses are based on operational factors such as operating hours and base loading factors; support factors such as maintenance action rates, maintenance times and costs; and non-economic factors. The purpose of the analyses is to establish the least cost feasible repair or discard decision alternative for performing the maintenance actions, and to influence equipment design in that direction.

D.2. GENERAL DESCRIPTION OF AIR

D.2.1. LOR Codes.

AIR is designed to simultaneously consider all parts of the system according to their arrangement in a part hierarchy, as illustrated by Figure D-1.

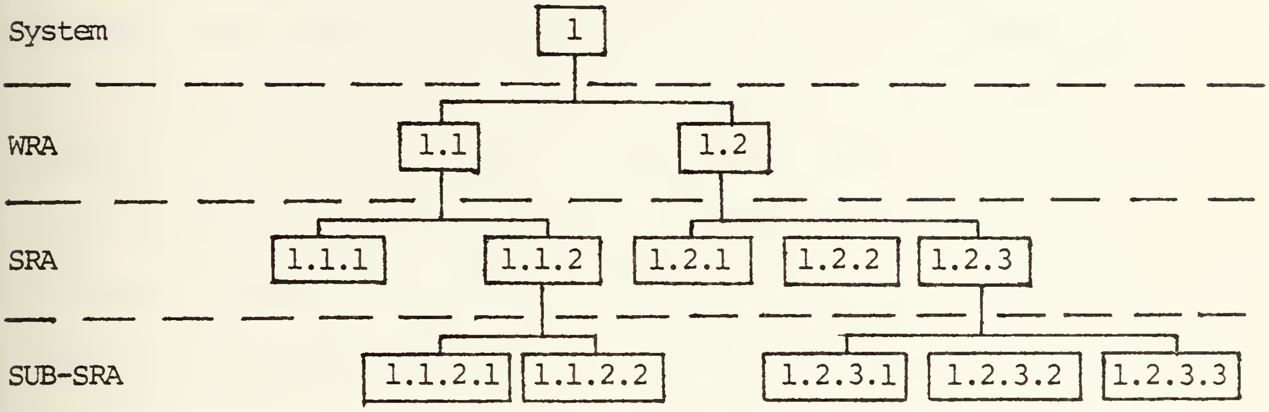


Figure D-1. System Breakdown in AIR

The computer model considers three levels of indenture: Weapon Replaceable Assembly (WRA) corresponding to LRU, Shop Replaceable Assembly (SRA) which corresponds to SRU, and SUB-SRA which are the sub-assemblies necessary for repair of SRA.

For each indenture level, four LOR alternatives are available. These are:

a) Intermediate Repair, which is the equivalent of local repair in other models and occurs at operational sites, including carriers.

b) Prime-Intermediate Repair, the equivalent of intermediate repair in other models, which occurs at a Prime Intermediate

Maintenance Activity (PIMA), a site with additional repair facilities compared to the basic operational site.

c) Depot Repair.

d) Discard.

Two major assumptions are used in the assignment of an LOR code to an item. (1) The LOR code assigned to a WRA does not depend on which of its SRA's failed (similarly for the SRA and its SUB-SRA). (2) An item can only be shipped to a level of repair higher than that for which its higher assembly is coded. Th-se two assumptions make it possible to assign a unique LOR posture to each item, and they will for each item give all possible combinations of LOR codes.

D.2.2. Spares Inventory

AIR makes a distinction between spares inventory for repair and discard policies. For the repair posture, inventory levels are calculated for each item, site, and LOR alternative. The on-site quantity is divided into two separate inventories: the Part 1 allowance- or Attrition quantity, against assemblies being repaired at a higher level of the maintenance organization; and the Part 2 allowance, or Rotatable Pool, against items being repaired at operational sites. The rules for operating sites are based on ASOINST 4441.15B [Ref. 16], and are summarized in MIL-STD-1390B(NAVY). The stock level for a given item and site is computed as the sum of the two amounts. A system stock is established to replace all items lost to the organization because they have been

condemned. Further, this stock contains a safety quantity to cover excess demands on the support pipeline.

For the discard alternative, the entire spares inventory is included in a single stock quantity, the "Discard Inventory," which is equal to the anticipated number of removals per year. No buffer stock is computed for the discard posture.

Some oddities, the reasons for which are not obvious, are as follows:

-- The objective is to provide a 95 percent confidence level against stock-out. This measure is not directly related to the required system effectiveness.

-- The calculation of inventory level is based on a Poisson arrival distribution, but the exact formula is not used. The approximation used seems to underestimate the quantity of spare parts needed.

-- The attrition quantity per site is a function of unit cost, the higher the cost, the lower the attrition quantity.

D.2.3. LSC Allocations

Life cycle logistic support costs are calculated for each item, each LOR alternative, and different cost categories. The costs are divided into allocable and non-allocable costs.

Allocable costs are those which can be associated with particular items, in contrast to non-allocable costs, those that are commonly used by several items.

AIR allocates costs to six major categories: (1) Inventory, including stocks, administration, repair and scrap material, and transportation; (2) Support equipment, which includes costs of hardware and support of the hardware; (3) Space required by inventory storage, repair work, and support equipment; (4) Labor; (5) Training of technical personnel; (6) Documentation. These cost elements are described in more detail below.

D.2.4. The Optimization Procedure

Some of the allocable costs depend on the LOR code of the item, and on that of its next higher assembly. Thus, for a WRA, four LOR decisions are possible, each of which is associated with a specific cost, while for an SRA, nine combinations exist. These possible assignments are given as follows:

Case	Assignment of ITEM (SRA)	Assignment of next higher ITEM (WRA)	
1	IMA	IMA	1
2	PIMA	IMA	
3	Depot	IMA	
4	Discard	IMA	
5	PIMA	PIMA	2
6	Depot	PIMA	
7	Discard	PIMA	
8	Depot	Depot	3
9	Discard	Depot	
		Discard	4

The four or nine costs corresponding to the different assignments are computed for each assembly, and for

its next higher assembly, if applicable. The optimization procedure is initiated by finding for each SUB-SRA the optimal LOR assignment for each possible assignment of its SRA. The optimal assignment of a Sub-SRA, given that its SRA is assigned to IMA, e.g., is the smallest cost from cases (1) through (4) in the table above. If the SRA is assigned to PIMA, it is the smallest cost of the cases (5) through (7); and if the SRA is assigned to Depot, it is the smallest cost of the cases (8) and (9). For every possible LOR code of an SRA, the optimal assignments of its Sub-SRA's are determined, along with their costs.

The next step is to find the optimal assignment of each SRA. The life support costs of the SRA are already available from step one. For each possible assignment of a WRA the optimal assignment of each of its SRA's is found, considering both the SRA costs and the costs of the optimal assignment of their Sub-SRA's. Having found the optimal support costs for each WRA considered at each level of repair, the costs of the optimal assignment of its SRA's are summed.

The final step is to find the optimal assignments of WRA's, taking into consideration the costs of its SRA's and Sub-SRA's. The following four quantities are calculated:

-- The LSC for the WRA if assigned to IMA plus the sum of the optimal costs for all its SRA's and Sub-SRA's, given this assignment.

-- The analogous quantity for the WRA assigned to PIMA.

-- The analogous quantity if the WRA is assigned to Depot.

-- The LSC if the WRA is discarded.

The smallest of these costs determines the LOR code for the WRA and its sub-units.

Non-allocable costs are assigned to the item at the highest indenture level for which they are common.

D.2.5. Input Data

A variety of input data must be prepared in order to describe the system being analyzed and the support organization. Special pre-designed forms facilitate the preparation for the analyst. The following categories of data are needed by the program:

-- Parameters and System Data:

Data defining the size of the problem, e.g., the number of sites, the number of systems per site, the number of man types, etc., and data needed by the overall operation of the model, such as life cycle period, cost factors, repair cycle times, and labor hourly rates.

-- Site Data:

Data defining and describing the different maintenance sites and the support activities such as site type, required days stock, system data, and distant repair data.

-- Identification:

Defining the various parts of the system being analyzed and their position in the parts hierarchy by a part number,

the number of the next higher assembly, and the item number.

-- Item Characteristics:

This set of data includes unit cost, MTBF, materials cost per reapir, scrap rates, and other descriptive data, such as weight and volume.

-- Manpower Data:

Describing the various kinds of manpower required to support the system. Included is training cost per technician, quantity needed, and attrition rates.

-- Task Data:

Defining and describing verify and repair tasks, and the associated requirements for manhours, support equipment, space, and documentation.

-- Other Input Data:

The analyst may specify alternatives in terms of pre-designating the LOR codes for some or all items. Further, he may specify sensitivity analysis to be performed for some of the input variables.

D.3. COST ELEMENT COMPUTATIONS

All cost calculations are based upon formulas included in MIL-STD-1390B(NAVY). Formulas are developed for repair and discard alternatives, as well as for land-based and carrier-based equipment.

The main differences in cost calculations for land-based and carrier-based equipment are that the required days of stock

and the transportation cost from the central stock are higher for the carrier based systems.

D.3.1. General Basis of Computations

The annual number of items received for repair at each level of the maintenance organization can be predicted, based upon the number of systems, the MTBF for the system, and the optimal LOR alternative. To obtain the actual number of repair tasks, corrections are made for items falsely removed, assemblies that are beyond the Capability of Maintenance (BCM) at a particular site, and the fraction of failed items that is scrapped. All these fractions are input data, which are used for computation of manpower, transportation, inventory, and other cost elements.

The present value of annual recurring costs is obtained by use of one of the following three discount factors:

-- Normal Discount Factor (NDF) is used with expenditures occurring as equal payments, starting one year hence and terminating at the end of the life cycle

$$NDF = \frac{(1 + DR)^{Y} - 1}{DR \times (1+DR)^{Y}}$$

where:

DR = Discount Rate;

Y = Number of years in the life cycle.

-- Present Discount Factor (PDF) is used with equal payments starting at the present and terminating one year prior to the

end of the life cycle

$$PDF = \frac{(1 + DR)^{Y} - 1}{DR \times (1 + DR)^{Y-1}}$$

-- Reduced Discount Factor (RDF) is used with equal payments starting two years hence and terminating at the end of the life cycle

$$RDF = \frac{(1 + DR)^{Y-1} - 1}{DR \times (1 + DR)^{Y}}$$

The model does not include the effect of inflation.

D.3.2. Inventory Costs

Included in this cost category are Inventory Administration Costs (IAC), Total Repairable Inventory Costs (TRC), Repair Scrap Costs (RSC), Repair Material Costs (RMC), and Transportation Costs (TC). The Total Inventory Cost (TIC) is

$$TIC = IAC + TRC + RSC + RMC + TC.$$

D.3.2.1. Inventory Administration Cost (IAC)

IAC is the cost of local management, entry, and retention of the repairable item and its peculiar components in the NSN system.

The equation used for IAC is

$$IAC = [IEC + (IRC + FAC \times NS) \times NDF] \times [1 + NPC]$$

where:

IEC = Item Entry Cost;

IRC = Item Retention Cost;

FAC = Field Supply Administration cost per item per site per year;

NS = Number of Sites Repairing the Item;

NDF = Normal Discount Factor;

NPC = Number of Peculiar Components.

The values of IEC and IRC are obtained from historical data.

D.3.2.2. Total Repairable Inventory Cost

The repairable inventory quantity consists of the Rotatble Pool Quantity (RPQ), the Attrition Quantity (AQ), and the System Stock Quantity (SSQ).

RPQ is stocked at the operating site to allow immediate replacement of items repaired locally. A Raw Rotatable Pool Quantity (RRPQ) is computed for each site as RRPQ = ANR * RPCT, where ANR is the annual number of repairs of the item, and RPCT is the repair cycle time for local repair measured in years. The RPQ is determined from the following table:

RRPQ	RPQ per site
<0.1	0
0.11-0.59	1
0.60-1.29	2
1.30-2.09	3
2.10-2.89	4
2.90-3.89	5
$\geq$ 3.9	INT{RRPQ + 1}

The Attrition Quantity (AQ) is, just as RPQ, stocked at the organizational level. AQ is meant to replace those items sent to higher level for repair. A Raw Attrition Quantity (RAQ) is computed per site for Local Repairs and for Off-Site Repairs.

The basic formula for RAQ is

RAQ = annual number of failures per item times the required years of stock at the site.

AQ is not dependent upon RAW only, but is a function of unit cost of the item as well. A table for AQ as a function of RAQ and unit cost is included in the AIR model. An example is:

unit cost ($):	<0.17	0.18-1.25	1.26-7.0	7.01-36	>36
AQ per site:	5	4	3	2	1

With the ability to fulfill a given demand as the measure of effectiveness, the favoring of inexpensive items may lead to a low system availability. Further, if RAW is less than 0.34, AQ is set to zero.

The System Stock Quantity (SSQ) is stocked at depots or designated resupply points. SSQ is procured to satisfy demands due to anticipated losses during the procurement leadtime and to account for repair cycle times exceeding required days stock. For each item, SSQ is computed as

$$SSQ = INT[FS + T_1 \times NP \times (1-BCMP) + T_2 \times ND]$$

where:

INT	=	Integer part (rounded off);
FS	=	Total number of the items scrapped during a period of time equal to the sum of the procurement leadtime and a safety period;
T_1	=	Repair cycle time from IMA to PIMA minus the required years stock at IMA. If this difference is negative, T_1 is set to zero;
NP	=	The total number of failed items of this type received at PIMA per year;
BCMP	=	Fraction beyond capability of maintenance at PIMA;
T_2	=	Repair cycle time from site or PIMA to depot minus required years stock.

As indicated, the SSQ is not affected by RPQ and AQ; for items having a reasonably high MTBF and if only few systems are procured, it is possible that all three quantities will be equal to zero.

The total repairable inventory quantity per item (TRQ) is

$$TRQ = RPQ + AQ + SSQ$$

and the total repairable inventory cost (TRC) is the summation for all item types of the system of TRQ times the unit cost of the items.

D.3.2.3. Repair Scrap Costs (RSC)

The repair scrap quantity is the inventory procured throughout the life cycle to replenish the system stock quantity due to items being scrapped during the repair process. The AIR model calculates an annual repair scrap quantity (RSQ) for each repair facility in the support organization. For each maintenance level a "scrap fraction" is contained among the input data, and the RSQ is computed as the annual number of repairs (for each item) multiplied by the fraction of items scrapped. The life cycle RSC is the summation for all items and all repair facilities of the product

$$\text{RSQ} \times \text{unit cost of item} \times \text{PDF}$$

(MIL-STD-1390B uses a normal discount factor, while AIR uses the present value discount factor (PDF), which is more correct.)

D.3.2.4. Repair Material Costs (RMC)

This cost element accounts for the cost of parts required per repair action, excluding parts which are included in the analysis. The total RMC is the summation of the cost at all repair facilities. For each item RMC is computed as

$$\text{RMC} = \text{ANR} \times \text{unit cost of item} \times \text{RMR} \times \text{PDF}$$

where:

ANR = Annual Number of Repairs for this item;

RMR = Repair Material Rate.

RMR has a great impact upon this cost element, as has the scrap fraction on Repair Scrap Cost. The values of these variables to be used must be based upon experience from similar equipment, the manufacturer's suggestion, and other relevant sources, but still uncertainty will exist.

D.3.2.5. Transportation Costs (TC)

In this model TC is an element of inventory costs. Included are the costs of packaging, handling, and transportation to and from operational, repair, and stockage sites. The costs are computed per site as functions of packaging and handling rates per cubic foot and transportation rates per pound.

In principle, the life cycle costs of transportation are computed as

$$TC = NDF \times \sum_{i,j} [AN(i,j) \times TRRP_{i,j} \times WI + PHR \times ISS]$$

where:

NDF = Normal Discount Factor;

$AN(i,j)$ = Annual number of items sent from site i to site j;

$TRRP_{i,j}$ = Transportation rate per pound from site i to site j;

WI = Weight of the item;

PHR = Packaging and handling rate per cubic foot;

ISS = Inventory storage space per item, cubic feet.

The procedure used by AIR may be suitable for the Navy, but for other organizations (especially in small countries) simpler, more specific, and less demanding methods may exist.

D.3.3. Support Equipment Costs (SEC)

SEC is computed as the sum of support equipment (TSE) acquisition cost (SEAC), which is a one time cost, and the annual cost of maintaining the support equipment (MSEC), which is computed as a fraction of the initial investment for support equipment.

Two types of TSE are considered in LOR decisions. First, an item may require Peculiar Ground Support Equipment (PGSE) for fault isolation or verification. Second, TSE may be designed to serve a group of items, in which case it is required at a repair facility if at least one member of the group is assigned for repair at this facility.

D.3.3.1. Peculiar Ground Support Equipment Costs

In the PGSE cost equations that follow, the total cost of one PGSE set is defined to include the unit acquisition cost and annual recurring support costs, the total amount of which is the Unit and Support Cost of a PGSE (USCPGSE).

$$USCPGSE = UCP \times [1 + \frac{SSEY1}{1+DR} + SSEYY \times RDF]$$

where:

UCP = Unit cost of the PGSE;

SSEY1 = Support cost rate for the first year;

DR = Discount rate;

SSEYY = Support cost rate for succeeding years;

RDF = Reduced discount factor.

The quantity of a PGSE required is a function of the LOR alternative and is computed for each item for IMA, PIMA, and Depot level repair.

The life cycle cost of PGSE is the summation for all types of PGSE at all repair facilities of the following product:

$$\text{USCPGSE} \times \text{NRS} \times \text{NS}$$

where NRS is the quantity of the PGSE required for this type of site, and NS is the number of sites.

D.3.3.2. Common Ground Support Equipment Costs

The life cycle cost of a set of common support equipment is computed using the formula

$$\text{USCCOMSE} = \text{UCC} \times [1 + \frac{\text{SSEY1}}{1 + \text{DR}} + \text{SSEYY} \times \text{RDF}],$$

where UCC is the unit cost of the common TSE and other variables are as for PGSE. A utilization factor is not used.

D.3.4. Space Costs

Space costs are computed as the sum of the cost of space for inventory, support equipment, and repair work. The factors involved in the computation are the number of items, the size of the items, and the cost of space. The

cost of space available to the government already is excluded.

Inventory Storage Space Cost (ISSC) is calculated for each storage facility:

$$ISSC = TQ \times CPY \times SPI \times NDF,$$

where TQ is the total quantity stored at this site, CPY is the cost of space per cubic foot per year for the site, SPI is the storage space per item, and NDF is the normal discount factor.

The cost of support equipment space (SESC) is computed per site:

$$SESC = NSE \times SR \times CSPY \times NDF,$$

where NSE is the number of support equipments at this site, SR is the space required per support equipment, and CSPY is the cost of space per square foot per year for the site.

The cost of repair work space is obtained quite analogously with the cost of support equipment space.

Finally, the total cost of space is the summation of all costs of space for all sites.

D.3.5. Labor Costs

The cost of maintenance labor is computed only for direct maintenance actions on the item itself. The labor cost is calculated for each site of the maintenance organization

as the sum of the costs of verify tasks and repair tasks. The cost of verify tasks is associated with the discard posture and is not included for repair cases, which only takes into account the cost of removing and replacing the failed lower-level parts; these will be piece parts if the given assembly is a lowest-level item.

The maintenance labor cost equations are too extensive to be reproduced. Some reasons for this are:

-- to find the least cost alternative, it is necessary for each item, to compute the labor costs for the following cases:

- IMA repair.
- The item is repaired at PIMA, its higher assembly at IMA.
- The item and its higher assembly are both repaired at PIMA.
- The item is repaired at Depot, its higher assembly at IMA.
- The item is repaired at Depot, its higher assembly at PIMA.
- The item and its higher assembly are both repaired at Depot.

-- Different labor cost per hour at different levels of the maintenance organization; even for one site, several different hourly rates can be used.

-- The model assumes that a fraction of items removed has no real failures ("Fraction of items falsely removed").

The general form of computation of the cost per site is as follows:

Cost of labor = (number of maintenance actions) $\times$ (manhours per maintenance action) $\times$ (cost per manhour).

As complex as the labor cost equations are, it is surprising that the only elements of the repair process included are the removal and the replacement of failed parts.

D.3.6. <u>Training Costs</u>

Training costs are computed for each LOR alternative. For the IMA repair case, a training cost is incurred for each operational site; additionally, costs occur for the back-up facility (PIMA or Depot). For the PIMA repair cases, training costs are incurred for each PIMA and Depot facility; discard training cost is included for each IMA site if the higher assembly is repaired at IMA level. For depot repair cases, training costs are incurred for each Depot; discard training costs are incurred for other sites, which repair the higher assembly.

The number of men to be trained per site is an input variable, with no relation to the number of manhours required, upon which the computation of maintenance labor costs is based.

The training costs are divided into the initial cost and the recurring cost due to personnel attrition. The training cost per site (TCPS) equation is:

$$TCPS = NMT \times TCPM \times (1 + PAR) \times NDF$$

where:

NMT = Number of men to be trained for this site;

TCPM = Training cost per man;

PAR = Personnel attrition rate for this site;

NDF = Normal discount factor.

TCPM is not specified, so it is possible to include all relevant elements of cost as described in Chapter III.

The total maintenance training cost is the summation of TCPS for all sites of the organization.

D.3.7. Documentation Cost

In AIR documentation includes the following elements: the drawings and specifications which make up the system technical manual, the Logistic Support Analyses Record (LSAR) preparation, provisioning lists, and other relevant documentation. The cost of documentation is the sum of the costs for each level of the support organization.

For equipment already in production, the cost of documentation will normally be marginal, and an estimate will be obtainable from the manufacturer.

D.4. OUTPUT REPORTS

The results of a run of the AIR model are presented in the following six reports:

a) Total LSC, a summary of costs by alternative and indenture level (WRA, SRA, Sub-SRA).

b) Item Summary Report with Maintenance Scheme, a summary of costs by alternative and item.

c) Breakdown of LSC, percentages are given by alternative, cost category, and indenture level.

d) Total Inventory Values, values are given by alternative and item.

e) Per Site Inventory Values, given by alternative, item, site, and type of inventory.

f) Sensitivity Analysis Report, a summary of LSC, associated LOR codes, and percentages are given by alternative and data set.

An alternative consists of a predesignation of LOR codings for some particular items; the model will decide the optimal solutions for the remaining items. Six standard alternatives are always included in a run. In addition, up to forty other alternatives may be specified by the analyst.

The six standard alternatives are:

a) All WRA's Discard;

b) All WRA's Local Reapir--All SRA's Discard;

c) All WRA's Local--All SRA's Local-Sub-SRA's optimized;

d) All WRA's Local--All SRA's PIMA-Sub-SRA's optimized;

e) All WRA's Local--All SRA's Depot-Sub-SRA's optimized;

f) Least-Cost Alternative, no predesignations of LOR codes are made.

Examples of such output reports are included in Appendix F.

D.5. AIR USED FOR REPAIR/DISCARD DECISIONS

AIR considers the discard alternative by comparing, for each possible LOR alternative, the difference in support costs for a repair versus a discard posture. The model is designed as a tool to be used during all phases of the life cycle and it does not place any restrictions on the level of repair policy. Therefore, the equations used for repair/discard decisions are much more complex than those developed in Chapter IV.

Since AIR does not allocate costs to the categories used in this thesis, and since the equations used by the model are given in MIL-STD-1390B, only fundamental differences between computations or between cost elements included in AIR and in the approximated formulas developed in Chapter IV will be discussed.

D.5.1. Maintenance Manpower Costs

AIR assumes that a discard action, if any, is performed at the organizational or intermediate level for assemblies having a unit cost of less than $5,000. More expensive items are discarded at depot level. The manhours required per discard action and per repair action are input data, but to obtain correct results from the model, it is

necessary in the "Time to Remove and Replace Failed Parts" to include all the other time elements of the repair action, and in "Labor Cost per Hour" to include overhead. If this is not done, the model will favor the repair alternative.

D.5.2. Cost of Test and Support Equipment

In AIR, "Discard Peculiar Support Equipment" (DPSE) may be used for checks and tests of an assembly discarded at failure. This cost is allocated to the maintenance site, that repairs the higher assembly. If a cost of DPSE is not entered, AIR will not use the cost of peculiar support equipment for repair purposes in computation of the costs of a discard action, but will set the cost of support equipment to zero.

D.5.3. Inventory Costs

The main weakness in the computation of inventory costs for discarded items is that AIR initially buys spares for one year only, even if the procurement lead time is more than that. This leads to a lower life cycle cost of discarded items than the equations used in Chapter IV suggest.

The procedure used by OPUS-VII (Appendix C) and the one used by AIR for determination of initial procurement of spares are so divergent that no real comparison is possible. In most cases, AIR's suggestion will be insufficient for fulfillment of a ninety five percent system availability, and if this is required, the cost of a repair alternative is underestimated.

D.5.4. Training Costs

In AIR a special training cost for the discard cases is given in the input data. For an item repaired at failure, different training costs are computed for each level of repair policy. For the organizational level, a repair training cost is incurred for each operational site and for the back-up facility (intermediate level or depot). For the intermediate level, a repair training cost is computed for this level and for the depot; further, discard training costs are included for each operational site. For the depot repair alternative, repair training costs are included for this site, and discard training costs are computed for the sites which repair the higher assembly.

D.5.5. Transportation Costs

For the discard cases, AIR computes this cost element as the cost of shipping an assembly from the resupply facility to the site where the item is discarded; by using a transportation rate of zero, it is possible to simulate that the item is stocked at this site.

For the repair cases, the transportation costs are computed as the sum of the costs of shipping the failed item to the site at which it is repaired and the transportation cost from the resupply facility to the repair site.

D.5.6. Other Elements of LSC

The costs of documentation are predetermined (input data to the program). If space not already available to the organization is needed, the different requirements for

a repair versus a discard policy must be estimated and included as input to the program.

D.5.7. Conclusions

The AIR model takes into consideration many of the cost elements judged as insensitive in the development of the simplified equations for repair/discard decisions (Chapter IV). Except for the limitations mentioned in Section 5.2.6., AIR is found to be adequate for evaluation of LSC and repair/discard decisions.

APPENDIX E

THE SIMPLE MODEL

E.1. INTRODUCTION

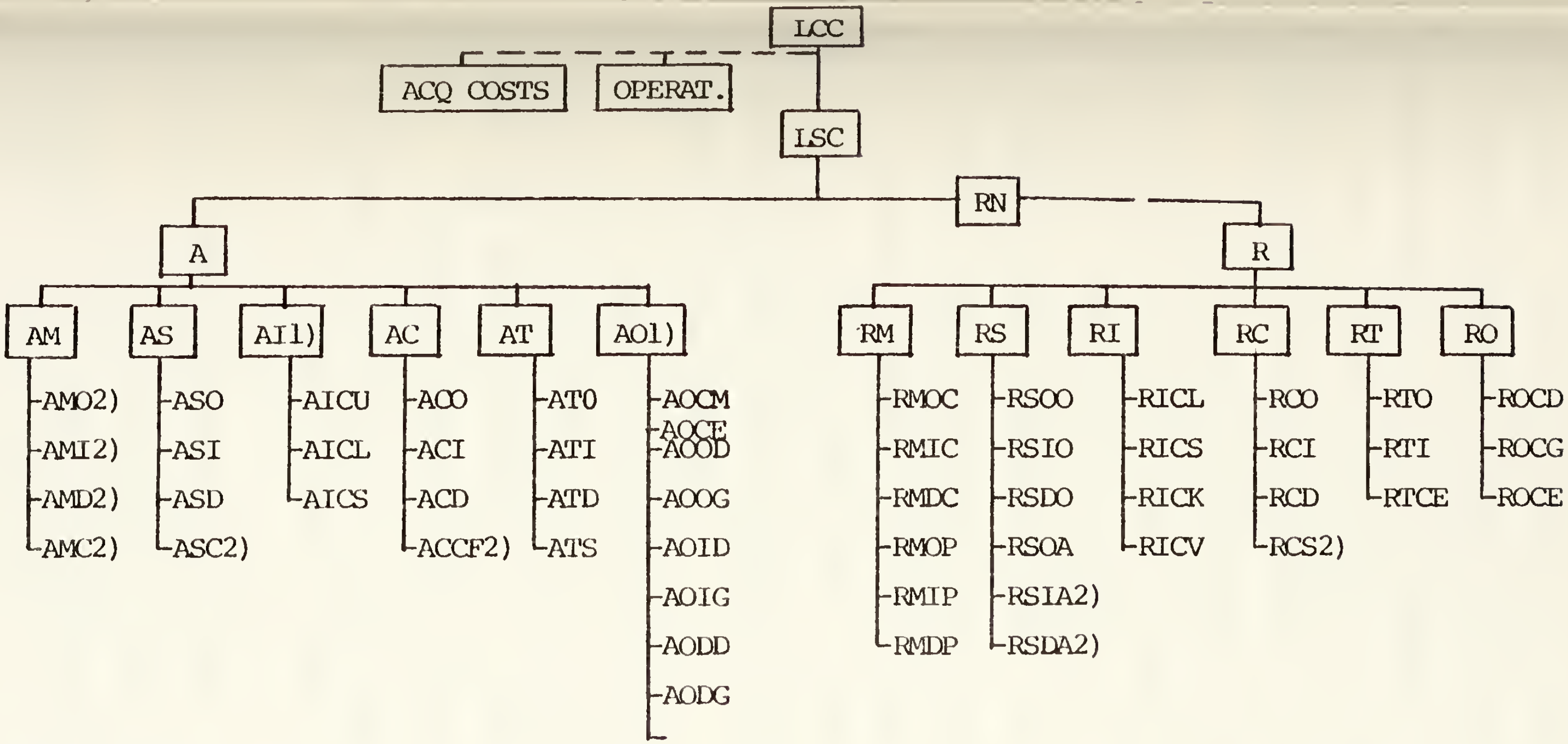
SIMPLE was programmed for two reasons. The first is that, in addition to AIR, it was needed for parts of the numerical analysis in Chapter VI. The second reason is a desire to illustrate that useful estimates of Life Support Costs (LSC) and its elements can be obtained without using a complex model.

All cost and delta-cost (repair/discard) equations are based on the general cost formulas developed in Chapters III and IV.

E.2. CHANGES FROM CHAPTER III

Changesto the cost breakdown illustrated in Figure 3-3 are marked by 1) in Figure E-1. Using OPUS-VII for computation of initial investment in spares, it is more convenient to compute AI as AICU + AICL + AICS (the sum of entering costs and initial investment in LRU's and SRU's). To make the output more illustrative the costs of documentation (AOCD) and space (AOCG) are divided into a cost per level of the support organization (AOOD, AOID, AODD and AOOG, AOIG, AODG, respectively).

Some cost elements [marked by 2) in Figure E-1] are not relevant to the example in Chapter VI. A zero cost for these elements is entered as input to the model.



Abbreviations:

First Letter:

A: Investment costs
R: Annual recurring costs

Second Letter:

M: Manpower
S: Test & Support equipm.
I: Inventory
C: Training
T: Transportation
O: Other costs
N: Total for the life cycle

Third Letter:

O: Organizational level
I: Intermediate level
D: Depot level
C: Common/all sites
S: Stockage sites

Fourth Letter:

A: Common
C: Corrective maintenance
D: Documentation
E: Other costs
F: Equipment
G: Space
K: Consumables and materials
L: LRU's
M: Meetings
O: Peculiar items
P: Preventive maintenance
U: Entering cost
V: Holding cost

Figure E-1. LSC Breakdown, SIMPLE

E.3. COST EQUATIONS

The cost equations used in SIMPLE are based upon Chapter III. Since the specific equations used in the model are designed for the system, the support organization, and the support policy stated in Chapter VI, such variables as cost per site of test and support equipment (common and peculiar) and documentation are assumed to be given (input data).

The initial procurement of LRU's and SRU's is computed by OPUS-VII and the cost is used as input to SIMPLE. In the example, the initial investment in repair parts is assumed insignificant and set to zero (in a real situation this cost would be known and should be included). For computation of the annual recurring cost of repair parts, fixed values are used per LRU and SRU repair (ACMCL and ACMCS, respectively). More accurate cost estimates require the use of a different value for each module.

An annual recurring cost of updating and maintaining documentation and maintaining space is computed as a fraction of the initial investment in these elements.

The main part of the source program and an alphabetically sorted list of input variable names are found in Sections E.5 and E.6. An example of input/output data is included in Appendix F.

E.4. DELTA COST, REPAIR/DISCARD

For each repairable module, SIMPLE computes the change in LSC if the module is discarded at failure. A negative value of "Delta Cost, LRU_i/SRU_j Disc. At Failure" [DLTL(i)

and DLTS(j)] among the output data indicates that, based on an economical evaluation only, this module should be discarded at failure.

The delta cost equations used in SIMPLE are based on the formulas discussed in Chapter IV.

E.5. THE SIMPLE PROGRAM*

```
C**********************************************************************
C
C                  PROGRAM SIMPLE,LSC MODEL
C
C**********************************************************************
C
C      DEFINITION OF FILES
C      ***********************
C
      CALL FRTCMS('FILEDEF ','11      ','DISK    ','FILE11  ',
     1'DATA    ','(       ','BLKSIZE ','133     ','PERM    ')
      CALL FRTCMS('FILEDEF ','10      ','DISK    ','FILE10  ',
     1'DATA    ','(       ','BLKSIZE ','133     ','PERM    ')
C
C**********************************************************************
C
C    OUTPUT DATA
C    ***********
C
C
      COMMON LSC,A,RN,R,TMANPW,TTSE,TINVEN,TTRAIN,TTRANS,TOTHER,
C
     +AM,AS,AI,AC,AT,AD,RM,RS,RI,RC,RT,RD,DLTL(6),DLTS(11),ASD,
C
     +ASCA,ASCC,ASI,ASIA,ASIC,ASD,ASDA,ASDC,AICL,AICS,AICU,
C
     +ACC,ACI,ACD,ACCF,ACCC,AOID,ACDC,AOCG,AOIG,AODG,AOCM
C
      COMMON ACCE,
C
     +RMCCN,RMCC,RMICN,RMIC,RMDCN,RMDC,RMCPN,RMCP,RMIPN,RMIP,
C
     +RMDPN,RMDP,RSCCN,RSCC,RSICN,RSIC,RSDCN,RSDC,RICLN,RICL,RICSN,
C
     +RICS,RICKN,RICK,RIIKN,RIIK,RIDKN,RIDK,RICVN,RICV,RCCN
C
      COMMON RCC,
C
     +RCIN,RCI,RCDN,RCD,RTCN,RTC,RTIN,RTI,RTCEN,RTCE,ROCCN,ROCD,
C
     +ROCGN,ROCG,ROCEN,ROCE,TNLRUF,TNSRUF,DF,RDF,
C
     +AFL(6),AFS(11)
C
C**********************************************************************
C
C       AM,AT,ACCF,ACCG,ACIG,ACDG,ACCM,AND ACCE ARE ENTERED AS BEST
C      ESTIMATES.AICL AND AICS ARE OUTPUT FROM OPUS-7.
C
C**********************************************************************
C    INPUT DATA AND CONSTANTS
C    ****************************
C**********************************************************************
C
      COMMON XMS,XMFL(6),XMFS(11),SCS,CL(6),CS(11)
```

---

*This printout exhibits only those parts which have been programmed by the authors. Additional parts adopted from Colonel Pålsson's program (Section 5.4.1) are omitted (such as definitions and read and write statements).

```
C
      COMMON MLRUS,MSRUS,NLRU(6),NSRU(11),NPRT,PPL(6),PPS(11)
C
      COMMON NS,NI,ND,ASCAL,ASIAL,ASDAU,CPSL(6),
C
     +CPSS(11),RLOL,RLIL,RLDL,TCAO,TCAI,TCAD,PRLTD,ANPAO
C
      COMMON ANPAI,
C
     +ANPAD,TPAO,TPAI,TPAD,ENTC,HOLC
C
      COMMON NMTO,NMTI,NMTD
C
      COMMON TCTO,TCTI,TCTD
C
      COMMON CDCR,
C
     +CDIR,CDDR,FACIN,CONL,CONS,ACMOL,ACMOS,ATTOL,ATTIL,ATTDL,
C
     +AVCOI,AVCID,AVCOD,CMOT,UDSK,SPMAIN,PCIL(6),PCIS(11),
C
     +DISRT,APFF,S1,S2,S3,NY
C
C
C*******************************************************************
C
C     END OF DATA
C     ***********
C*******************************************************************
C
      REAL LSC,NY,MLRUS,MSRUS,NLRU,NSRU,
C
     +NPRT,NS,NI,ND,NMTO,NMTI,NMTD
C
C*******************************************************************
C
C   CALCULATION OF LIFE SUPPORT COST (LSC)
C   **************************************
C*******************************************************************
C
C   CONTROL-BLOCK
C   *************
C
C   THIS BLOCK CONTROLS THE UTILIZATION
C   OF THE FOLLOWING EQUATIONS.
C***************************************
C
      GO TO(2621,
C
     +2625,2620,2600,2725,2750,2700,2825,2850,2800,3100,3200,
C
     +3350,3600,3700,3800,4550,4600,4650,1201,5100,5125,5150,5200,
C
     +5225,5250,5600,5700,5800,6100,6200,6325,6350,6300,6400,6600,
C
```

```
     +6700,6800,7100,7200,7300,7600,7700,7800,2000,2500,3000,3500,        XX
C                                                                         XX
     +4000,4500,5000,5500,6000,6500,7000,7500,1100,1200,8006,8016,        XX
C                                                                         XX
     +8008,8018,1199,1101,1211,1301,1401,1501,1601,                       XX
C                                                                         XX
     +1000,9999),JEK                                                      XX
C                                                                         XX
C*************************************************************************XX
C                                                                         XX
C    LIFE SUPPORT COST EQUATIONS USED IN SIMPLE                           XX
C    ******************************************                           XX
C                                                                         XX
C*************************************************************************XX
C**    LIFE SUPPORT COSTS,TOTAL                                           XX
C                                                                         XX
1000   LSC = A+RN                                                         XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**    LSC,MANPOWER                                                       XX
C                                                                         XX
1101   TMANPW = AM+RM                                                     XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**     LSC,TEST AND SUPPORT EQUIPMENT                                    XX
C                                                                         XX
1211   TTSE = AS+RS                                                       XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**     LSC,INVENTORY                                                     XX
C                                                                         XX
1301   TINVEN = AI+RI                                                     XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**     LSC,TRAINING                                                      XX
C                                                                         XX
1401   TTRAIN = AC+RC                                                     XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**     LSC,TRANSPORTATION                                                XX
C                                                                         XX
1501   TTRANS = AT+RT                                                     XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**     LSC,OTHER ELEMENTS                                                XX
C                                                                         XX
1601   TOTHER = AO+RO                                                     XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**      INITIAL INVESTMENT,TOTAL                                         XX
C                                                                         XX
1100   A = AM+AS+AI+AC+AT+AO                                              XX
       GO TO 500                                                          XX
C*************************************************************************XX
C**        RECURRING COSTS,NY YEARS                                       XX
```

```
C
1200  RN = RM+RS+RI+RC+RT+RO
      GO TO 500
C*****************************************************************************
C**       INITIAL MANPOWER COSTS,EXCL. TRAINING
C
2000  AM = 0.
      GO TO 500
C*****************************************************************************
C**       TESE,INITIAL INVESTMENT
C
2500  AS = ASO+ASI+ASD
      GO TO 500
C*****************************************************************************
C**       INVENTORY,INITIAL INVESTMENT
C
3000  AI = AICL+AICS+AICU
      GO TO 500
C*****************************************************************************
C**       TRAINING,INITIAL
C
3500  AC = ACO+ACI+ACD+ACCF
      GO TO 500
C*****************************************************************************
C**       TRANSPORTATION,INITIAL COSTS
C
4000  AT = 0.
      GO TO 500
C*****************************************************************************
C**       OTHER INVESTMENT COSTS
C
4500  AO = AOCO+AOIO+AODO+AOOG+AOIG+AODG+AOOM+AOOE
      GO TO 500
C*****************************************************************************
C**       MANPOWER COSTS,RECURRING,NY YEARS
C
5000  RM = RMOON+RMION+RMDON+RMOPN+RMIPN+RMDPN
      GO TO 500
C*****************************************************************************
C**       SUPPORT OF TESE,NY YEARS
C
5500  RS = RSOON+RSION+RSDON
      GO TO 500
C*****************************************************************************
C**       INVENTORY,RECURRING COSTS,NY YEARS
C
6000  RI = RICLN+RICSN+RICKN+RICWN
      GO TO 500
C*****************************************************************************
C**       TRAINING,RECURRING COSTS,NY YEARS
C
6500  RC = RCON+RCIN+RCDN
      GO TO 500
C*****************************************************************************
C**       TRANSPORTATION COSTS,NY YEARS
```

```
C
7000  RT = RTCN+RTIN+RTCEN
      GO TO 500
C**************************************************************************************************
C**       OTHER RECURRING COSTS,NY YEARS
C
7500  CONTINUE
      RC = RCCCN+RCCGN+RCCEN
      GO TO 500
C*****************************************************************
C
2600  CONTINUE
      ASC = ASCA+ASCO
      GO TO 500
C*****************************************************************
C
2625  CONTINUE
      ASCA = ASCAL*NS
      GO TO 500
C*****************************************************************
C
2620  ASCO = 0.
      DO 2651 I=1,6
         ASCO=ASCO+CPSL(I)*NS
2651  CONTINUE
      GO TO 500
C*****************************************************************
C
2700  ASI = ASIA+ASIO
      GO TO 500
C*****************************************************************
C
2725  ASIA = ASIAL*NI
      GO TO 500
C*****************************************************************
C
2750  ASIO = ASCO*NI/NS
      DO 2751 J=1,11
         ASIO=ASIO+CPSS(J)*NI
2751  CONTINUE
      GO TO 500
C*****************************************************************
C
2800  ASD = ASDA+ASDO
      GO TO 500
C*****************************************************************
C
2825  ASDA = ASDAL*ND
      GO TO 500
C*****************************************************************
C
2850  ASDO = 0.
      DO 2851 J=1,11
         ASDO=ASDO+CPSS(J)*ND
2851  CONTINUE
```

```
      GO TO 500
C*************************************************
C
3100  AICL = 0.
      DO 3101 I =1,6
        AICL=AICL+PCIL(I)
3101  CONTINUE
      GO TO 500
C*************************************************
3200  AICS = 0.
      DO 3201 J=1,11
        AICS=AICS+PCIS(J)
3201  CONTINUE
      GO TO 500
C*************************************************


3350  AICL = (NLRUS*(NS+NI)+MSRUS*(NI+ND)+NPRT*ND)*ENTC
      GO TO 500
C*************************************************
C
3600  ACO = NMTO*TCTO*NS
      GO TO 500
C*************************************************
C
3700  ACI = NMTI*TCTI*NI
C
      GO TO 500
C*************************************************
C
3800  ACD = NMTD*TCTD*ND
      GO TO 500
C*************************************************
C
4550  ACOD = CDOR*NS
      GO TO 500
C*************************************************
C
4600  ACID = CDIR*NI
      GO TO 500
C*************************************************
C
4650  ACDD = CDDR*ND
      GO TO 500
C**********************************************************************
C
1199  CONTINUE
      R = RMOC+RMIC+RMDC+RMOP+RMIP+RMDP+RSOC+RSIC+RSDC+RICL+RICS+
     +RICK+RICV+RCO+RCI+RCD+RTO+RTI+RTD+RCOD+RCOG+RCOE
      GO TO 500
C**********************************************************************
C
1201  CONTINUE
      IF (DISRT.LE.0.) GO TO 1202
      DF = (1.-(1.+DISRT/100)**(-NY))/(DISRT/100)
```

```
      RDF = (1.-(1.+DISRT/100)**(-NY+2.))/(DISRT/100)                    XX
      GO TO 500                                                          XX
1202  CONTINUE                                                           XX
      DF = NY                                                            XX
      RDF= NY-2.                                                         XX
      GO TO 500                                                          XX
C*****************************************************************       XX
C                                                                        XX
5100  RMOC = (APPF*365/XMS)*NS*RLOL*TCAD                                 XX
      RMOCN = RMOC*DF                                                    XX
      GO TO 500                                                          XX
C**************************************************************          XX
C                                                                        XX
5125  TNLRUF = 0.                                                        XX
      DO 5126 I=1,6                                                      XX
         TNLRUF=TNLRUF+NS*NLRU(I)*APPF*365/XMFL(I)                       XX
5126  CONTINUE                                                           XX
      RMIC = TNLRUF*TCAI*RLIL                                            XX
      RMICN = RMIC*DF                                                    XX
      GO TO 500                                                          XX
C**************************************************************          XX
C                                                                        XX
5150  TNSRUF = 0.                                                        XX
      DO 5151 J=1,11                                                     XX
         TNSRUF=TNSRUF+NSRU(J)*NS*APPF*365/XMFS(J)                       XX
5151  CONTINUE                                                           XX
      RMOC = TNSRUF*RLOL*TCAD                                            XX
      RMOCN = RMOC*DF                                                    XX
      GO TO 500                                                          XX
C                                                                        XX
C***************************************************************         XX
C                                                                        XX
5200  CONTINUE                                                           XX
      RMOP = NS*ANPAO*TPAO*RLOL                                          XX
      RMOPN = RMOP*DF                                                    XX
      GO TO 500                                                          XX
C***************************************************                     XX
C                                                                        XX
5225  CONTINUE                                                           XX
      RMIP = NS*ANPAI*TPAI*RLIL                                          XX
      RMIPN = RMIP*DF                                                    XX
      GO TO 500                                                          XX
C***************************************************                     XX
C                                                                        XX
5250  CONTINUE                                                           XX
      RMOP = NS*ANPAO*TPAO*RLOL                                          XX
      RMOPN = RMOP*DF                                                    XX
      GO TO 500                                                          XX
C***************************************************                     XX
C                                                                        XX
5600  CONTINUE                                                           XX
      RSCC = ASCO*FACIN                                                  XX
      RSCCN = RSCC*DF                                                    XX
      GO TO 500                                                          XX
C***************************************************                     XX
```

```
C                                                                    XX
5700  CONTINUE                                                       XX
      RSIC = ASIC*FACIN                                              XX
      RSICN = RSIC*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
5800  CONTINUE                                                       XX
      RSDC = ASDC*FACIN                                              XX
      RSDCN = RSDC*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6100  CONTINUE                                                       XX
      RICL = 0.                                                      XX
      DO 6101 I=1,6                                                  XX
        RICL=RICL+(APPF*NS*NLRU(I)*365/XMFL(I))*CONL*CL(I)           XX
6101  CONTINUE                                                       XX
      RICLN = RICL*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6200  CONTINUE                                                       XX
      RICS = 0.                                                      XX
      DO 6201 J=1,11                                                 XX
        RICS= RICS+(APPF*NS*NSRU(J)*365/XMFS(J))*CONS*CS(J)          XX
6201  CONTINUE                                                       XX
      RICSN = RICS*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6300  RICK = RIIK+RICK                                               XX
      RICKN = RICK*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6325  RIIK = TNLRLF*ACMCL                                            XX
      RIIKN = RIIK*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6350  RICK = TNSRLF*ACMCS                                            XX
      RICKN = RICK*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6400  RICV = (NLRUS*NS+(MLRUS+MSRUS)*NI+(MSRUS+NPRT)*ND)*HCLC        XX
      RICVN = RICV*DF                                                XX
      GO TO 500                                                      XX
C**************************************************************      XX
C                                                                    XX
6600  RCC = ACC*ATTCL                                                XX
      RCCN = RCC*DF                                                  XX
      GO TO 500                                                      XX
C**************************************************************      XX
```

```
C                                                                        XX
6700  RCI = ACI*ATTIL                                                    XX
      RCIN = RCI*DF                                                      XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
6800  RCD = ACD*ATTDL                                                    XX
      RCDN = RCD*DF                                                      XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7100  RTC = TNLRLF*AVDCI*CMOT                                            XX
      RTCN = RTC*DF                                                      XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7200  RTI = TNSRLF*AVDID*CMOT                                            XX
      RTIN = RTI*DF                                                      XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7300  RTCE = (ANPAI*AVDCI+ANPAD*AVDOD)*CMOT                              XX
      RTCEN = RTCE*DF                                                    XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7600  RCCD = (ACCD+ACID+ACDD)*UDSK                                       XX
      RCCDN = RCCD*DF                                                    XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7700  RCCG = (ACCG+ACIG+ACDG)*SPMAIN                                     XX
      RCCGN = RCCG*DF                                                    XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
2621  CONTINUE                                                           XX
      DO 2622 I=1,6                                                      XX
        CL(I)=CL(I)*S3                                                   XX
        XMFL(I)=XMFL(I)*S1                                               XX
2622  CONTINUE                                                           XX
      SCS=SCS*S3                                                         XX
      XMS=XMS*S1                                                         XX
      DO 2623 J=1,11                                                     XX
        CS(J)=CS(J)*S3                                                   XX
        XMFS(J)=XMFS(J)*S1                                               XX
2623  CONTINUE                                                           XX
      TCAC=TCAC*S2                                                       XX
      TCAI=TCAI*S2                                                       XX
      TCAD=TCAD*S2                                                       XX
      GO TO 500                                                          XX
C*************************************************************          XX
C                                                                        XX
7800  RCCE = (ACCN+ACCE)*0.1                                             XX
      RCCEN = RCCE*DF                                                    XX
```

```
      GO TO 500                                                           XX
C*************************************************************           XX
C                                                                         XX
8006  CONTINUE                                                            XX
      DO 8007 I=1,6                                                       XX
        AFL(I)=NS*NLRU(I)*APPF*365/XMFL(I)                                XX
8007  CONTINUE                                                            XX
      GO TO 500                                                           XX
C*************************************************************           XX
C                                                                         XX
8016  CONTINUE                                                            XX
      DO 8017 J=1,11                                                      XX
        AFS(J)=NS*NSRU(J)*APPF*365/XMFS(J)                                XX
8017  CONTINUE                                                            XX
      GO TO 500                                                           XX
C*************************************************************************  XX
C                                                                         XX
C   COST OF REPAIR MINUS COST OF DISCARD                                  XX
C   ************************************                                  XX
C   LRU"S:                                                                XX
C   *****                                                                 XX
C                                                                         XX
8008  CONTINUE                                                            XX
      DO 8009 I=1,6                                                       XX
          DLTL(I)=0.                                                      XX
          DLTL(I)=2.0*AFL(I)*CL(I)+(1.-CONL)*AFL(I)*RDF*CL(I)-PCIL(I)     XX
          DLTL(I)=DLTL(I)-(PLIL*TCAI+PRLTD*RLDL*TCAD)*DF*AFL(I)           XX
          DLTL(I)=DLTL(I)-CPSL(I)*(1.+DF*FACIN)*NI                        XX
          DLTL(I)=DLTL(I)-(ENTC+DF*HOLC)*(PPL(I)+1.)*ND                   XX
          DLTL(I)=DLTL(I)-(ACMCL+ACMCS)*DF*AFL(I)                         XX
          DLTL(I)=DLTL(I)-(AVDOI+AVDIC-.5*AVDOD)*CMOT*DF*AFL(I)           XX
           IF(CL(I).GT.5000.) GO TO 8027                                  XX
          DLTL(I)=DLTL(I)-((1.-RLDL)*TCAD+AVDIC*CMOT)*DF*AFL(I)           XX
8027  CONTINUE                                                            XX
8009  CONTINUE                                                            XX
      GO TO 500                                                           XX
C*************************************************************************  XX
C   SRU"S:                                                                XX
C   *****                                                                 XX
C                                                                         XX
8018  CONTINUE                                                            XX
      DO 8019 J=1,11                                                      XX
        DLTS(J)=0.                                                        XX
        DLTS(J)=2.0*CS(J)*AFS(J)+RDF*CS(J)*AFS(J)*(1.0-CONS)-PCIS(J)      XX
        DLTS(J)=DLTS(J)-DF*AFS(J)*PRLTD*RLDL*TCAD                         XX
        DLTS(J)=DLTS(J)-CPSS(J)*(1.0+DF*FACIN)*NI                         XX
        DLTS(J)=DLTS(J)-(ENTC+DF*HOLC)*(PPS(J)+1.)*ND                     XX
        DLTS(J)=DLTS(J)-(ACMCS+AVDIC*CMOT/2.)*DF*AFS(J)                   XX
          IF(CS(J).GT.5000.) GO TO 8014                                   XX
       DLTS(J)=DLTS(J)-(.5*AVDID*CMOT+(1-PRLTD)*RLDL*TCAD)*DF*AFS(J)      XX
8014  CONTINUE                                                            XX
8019  CONTINUE                                                            XX
      GO TO 500                                                           XX
C*************************************************************************  XX
C                                                                         XX
```

```
9999  CONTINUE                                                              XX
      RETURN                                                                XX
      END                                                                   XX
C*******************************************************************        XX
```

E.6. VARIABLES USED IN SIMPLE

The following alphabetically sorted variable list includes the variables used in SIMPLE:

```
**************************************************

       VARIABLE NAMES USED IN SIMPLE
          (ALPHABETICALLY SORTED)

**************************************************
 ACMCL     : CONSUM.&MAT./LRU REPAIR,AVERAGE
 ACMCS     : CONSUM.&MAT./SRU REPAIR,AVERAGE
 ANPAC     : ANNUAL # OF PREV.MAINT.ACT.DEP-LEVEL
 ANPAI     : ANNUAL # OF PREV.MAINT.ACT.INT-LEVEL
 ANPAC     : ANNUAL # OF PREV.MAINT.ACT.ORG-LEVEL
 ACIG      : SPACE COSTS,INT-LEVEL
 AOOG      : SPACE COSTS,ORG-LEVEL
 ACDG      : SPACE COSTS,DEP-LEVEL
 APPF      : OPERATING HOURS/SYSTEM-DAY
 ASDAL     : T&SE,COMMON,COST/SITE,DEP-LEVEL
 ASIAL     : T&SE,COMMON,COST/SITE,INT-LEVEL
 ASOAL     : T&SE,COMMON,COST/SITE,ORG-LEVEL
 ATTCL     : TECHNICIAN,ATTRITION RATE,DEP-LEVEL
 ATTIL     : TECHNICIAN,ATTRITION RATE,INT-LEVEL
 ATTCL     : TECHNICIAN,ATTRITION RATE,ORG-LEVEL
 AVDIC     : DISTANCE,MILES,INT-DEP-LEVEL,ROUND TRIP
 AVDCD     : DISTANCE,MILES,ORG-DEP-LEVEL,ROUND TRIP
 AVDCI     : DISTANCE,MILES,ORG-INT-LEVEL,ROUND TRIP
 CDDR      : DOCUMENTATION COST/SITE,DEP-LEVEL
 CDIR      : DOCUMENTATION COST/SITE,INT-LEVEL
 CDNL      : CONDEMNATION RATE,LRU REPAIR
 CDNS      : CONDEMNATION RATE,SRU REPAIR
 CDOR      : DOCUMENTATION COST/SITE,ORG-LEVEL
 CL1       : UNIT COST,LRU1
```

```
CL2      : UNIT COST,LRU2
CL3      : UNIT COST,LRU3
CL4      : UNIT COST,LRU4
CL5      : UNIT COST,LRU5
CL6      : UNIT COST,LRU6
CMOT     : TRANSPORTATION,COST/MILE
CPSL1    : T&SE,PECULIAR,LRU1,UNIT COST
CPSL2    : T&SE,PECULIAR,LRU2,UNIT COST
CPSL3    : T&SE,PECULIAR,LRU3,UNIT COST
CPSL4    : T&SE,PECULIAR,LRU4,UNIT COST
CPSL5    : T&SE,PECULIAR,LRU5,UNIT COST
CPSL6    : T&SE,PECULIAR,LRU6,UNIT COST
CPSS1    : T&SE,PECULIAR,SRU1,UNIT COST
CPSS2    : T&SE,PECULIAR,SRU2,UNIT COST
CPSS3    : T&SE,PECULIAR,SRU3,UNIT COST
CPSS4    : T&SE,PECULIAR,SRU4,UNIT COST
CPSS5    : T&SE,PECULIAR,SRU5,UNIT COST
CPSS6    : T&SE,PECULIAR,SRU6,UNIT COST
CPSS7    : T&SE,PECULIAR,SRU7,UNIT COST
CPSS8    : T&SE,PECULIAR,SRU8,UNIT COST
CPSS9    : T&SE,PECULIAR,SRU9,UNIT COST
CPSS10   : T&SE,PECULIAR,SRU10,UNIT COST
CPSS11   : T&SE,PECULIAR,SRU11,UNIT COST
CS1      : UNIT COST,SRU1
CS2      : UNIT COST,SRU2
CS3      : UNIT COST,SRU3
CS4      : UNIT COST,SRU4
CS5      : UNIT COST,SRU5
```

```
CS6      : UNIT COST,SRU6
CS7      : UNIT COST,SRU7
CS8      : UNIT COST,SRU8
CS9      : UNIT COST,SRU9
CS10     : UNIT COST,SRU10
CS11     : UNIT COST,SRU11
DISRT    : DISCOUNT RATE,%
ENTC     : INVENTORY ENTERING COST
FACIN    : T&SE,PECULIAR,FRACTION,ANNUAL COST/INV
HOLC     : INVENTORY HOLDING COST
NLRUS    : NUMBER OF DIFFERENT LRU'S
NSRUS    : NUMBER OF DIFFERENT SRU'S
ND       : NUMBER OF DEP-LEVEL SITES
NI       : NUMBER OF INT-LEVEL SITES
NLRU1    : NUMBER OF LRU1/SYSTEM
NLRU2    : NUMBER OF LRU2/SYSTEM
NLRU3    : NUMBER OF LRU3/SYSTEM
NLRU4    : NUMBER OF LRU4/SYSTEM
NLRU5    : NUMBER OF LRU5/SYSTEM
NLRU6    : NUMBER OF LRU6/SYSTEM
NMTD     : # OF TRAINEE/DEPOT SITE,INITIAL
NMTI     : # OF TRAINEE/INTERM. SITE,INITIAL
NMTO     : # OF TRAINEE/OPERATIONAL SITE,INITIAL
NPRT     : NUMBER OF CONSUMABLES IN INVENTORY
NS       : NUMBER OF OPERATIONAL SITES
NSRU1    : NUMBER OF SRU1/SYSTEM
NSRU2    : NUMBER OF SRU2/SYSTEM
```

```
NSRU3     : NUMBER OF SRU3/SYSTEM
NSRU4     : NUMBER OF SRU4/SYSTEM
NSRU5     : NUMBER OF SRU5/SYSTEM
NSRU6     : NUMBER OF SRU6/SYSTEM
NSRU7     : NUMBER OF SRU7/SYSTEM
NSRU8     : NUMBER OF SRU8/SYSTEM
NSRU9     : NUMBER OF SRU9/SYSTEM
NSRU10    : NUMBER OF SRU10/SYSTEM
NSRU11    : NUMBER OF SRU11/SYSTEM
NY        : LIFE CYCLE PERIOD,YEARS
PCIL1     : INITIAL PROVISIONING COST,LRU1 (OPUS)
PCIL2     : INITIAL PROVISIONING COST,LRU2 (OPUS)
PCIL3     : INITIAL PROVISIONING COST,LRU3 (OPUS)
PCIL4     : INITIAL PROVISIONING COST,LRU4 (OPUS)
PCIL5     : INITIAL PROVISIONING COST,LRU5 (OPUS)
PCIL6     : INITIAL PROVISIONING COST,LRU6 (OPUS)
PCIS1     : INITIAL PROVISIONING COST,SRU1 (OPUS)
PCIS2     : INITIAL PROVISIONING COST,SRU2 (OPUS)
PCIS3     : INITIAL PROVISIONING COST,SRU3 (OPUS)
PCIS4     : INITIAL PROVISIONING COST,SRU4 (OPUS)
PCIS5     : INITIAL PROVISIONING COST,SRU5 (OPUS)
PCIS6     : INITIAL PROVISIONING COST,SRU6 (OPUS)
PCIS7     : INITIAL PROVISIONING COST,SRU7 (OPUS)
PCIS8     : INITIAL PROVISIONING COST,SRU8 (OPUS)
PCIS9     : INITIAL PROVISIONING COST,SRU9 (OPUS)
PCIS10    : INITIAL PROVISIONING COST,SRU10 (OPUS)
PCIS11    : INITIAL PROVISIONING COST,SRU11 (OPUS)
PPL1      : NUMBER OF PECULIAR PARTS,LRU1
```

```
PPL2     : NUMBER OF PECULIAR PARTS,LRU2
PPL3     : NUMBER OF PECULIAR PARTS,LRU3
PPL4     : NUMBER OF PECULIAR PARTS,LRU4
PPL5     : NUMBER OF PECULIAR PARTS,LRU5
PPL6     : NUMBER OF PECULIAR PARTS,LRU6
PPS1     : NUMBER OF PECULIAR PARTS,SRU1
PPS2     : NUMBER OF PECULIAR PARTS,SRU2
PPS3     : NUMBER OF PECULIAR PARTS,SRU3
PPS4     : NUMBER OF PECULIAR PARTS,SRU4
PPS5     : NUMBER OF PECULIAR PARTS,SRU5
PPS6     : NUMBER OF PECULIAR PARTS,SRU6
PPS7     : NUMBER OF PECULIAR PARTS,SRU7
PPS8     : NUMBER OF PECULIAR PARTS,SRU8
PPS9     : NUMBER OF PECULIAR PARTS,SRU9
PPS10    : NUMBER OF PECULIAR PARTS,SRU10
PPS11    : NUMBER OF PECULIAR PARTS,SRU11
PRLTC    : RATIO,DISCARD TO REPAIR MANHOURS
RLDL     : MANHOUR RATE,DEP-LEVEL
RLIL     : MANHOUR RATE,INT-LEVEL
RLOL     : MANHOUR RATE,ORG-LEVEL
SCS      : UNIT COST,SYSTEM
SPMAIN   : SPACE,MAINT. OF,FRACT. ANN./INV.COST
S1       : MTBF,MULTIPLICATION FACTOR
S2       : CORR.MAINT-TIME,MULTIPLICATION FACTOR
S3       : UNIT COST,MULTIPLICATION FACTOR
TCAD     : AVERAGE MANHOURS/CORR.MAINT.ACT.DEP-LEV
TCAI     : AVERAGE MANHOURS/CORR.MAINT.ACT.INT-LEV
```

```
TCAC     : AVERAGE MANHOURS/CORR.MAINT.ACT.ORG-LEV
TCTD     : COST/TRAINEE,COURSE,DEP-LEVEL
TCTI     : COST/TRAINEE,COURSE,INT-LEVEL
TCTO     : COST/TRAINEE,COURSE,ORG-LEVEL
TPAD     : AVERAGE TIME/PREV.MAINT.ACT.DEP-LEVEL
TPAI     : AVERAGE TIME/PREV.MAINT.ACT.INT-LEVEL
TPAO     : AVERAGE TIME/PREV.MAINT.ACT.ORG-LEVEL
UDSK     : DOCUMENTATION,FRACTION,ANN./INV. COST
XMFL1    : MTBF,LRU1
XMFL2    : MTBF,LRU2
XMFL3    : MTBF,LRU3
XMFL4    : MTBF,LRU4
XMFL5    : MTBF,LRU5
XMFL6    : MTBF,LRU6
XMFS1    : MTBF,SRU1
XMFS2    : MTBF,SRU2
XMFS3    : MTBF,SRU3
XMFS4    : MTBF,SRU4
XMFS5    : MTBF,SRU5
XMFS6    : MTBF,SRU6
XMFS7    : MTBF,SRU7
XMFS8    : MTBF,SRU8
XMFS9    : MTBF,SRU9
XMFS10   : MTBF,SRU10
XMFS11   : MTBF,SRU11

***********************
```

APPENDIX F

INPUT/OUTPUT DATA

F.1. INTRODUCTION

This appendix includes four categories of computer printouts:

a) Input data for the models AIR, OPUS-VII, and SIMPLE.

b) Examples of AIR output.

c) Examples of OPUS-VII output.

d) Examples of SIMPLE output.

F.2. INPUT DATA

Table F-1 includes an alphabetically sorted listing of the input data variables used in the three models. For each variable, its name, meaning, and numerical values used in the example are included. The letters S, A, and O correspond with the models (SIMPLE, AIR, and OPUS-VII, respectively).

TABLE F-1. Input Data

```
FILE: SCRT     DATA     A   NAVAL POSTGRADUATE SCHOOL

*************************************************************************

                              INPUT DATA
                              **********

S=SIMPLE                         A=AIR                               O=OPUS

*************************************************************************

15.       ACMCL   : CONSUM.&MAT./LRU REPAIR,AVERAGE                   S
35.       ACMCS   : CONSUM.&MAT./SRU REPAIR,AVERAGE                   S
1.        ANPAD   : ANNUAL # OF PREV.MAINT.ACT.DEP-LEVEL              S
12.       ANPAI   : ANNUAL # OF PREV.MAINT.ACT.INT-LEVEL              S
365.      ANPAO   : ANNUAL # OF PREV.MAINT.ACT.ORG-LEVEL              S
0.        ACOG    : SPACE COSTS,DEP-LEVEL                             S
14000.    AOIG    : SPACE COSTS,INT-LEVEL                             S
24000.    AOOG    : SPACE COSTS,ORG-LEVEL                             S
24.       APPF    : OPERATING HOURS/SYSTEM-DAY                        S,A,O
1.8       ARTL    : ACTIVE REPAIR TIME LRU"S                          A,O
1.8       ARTS    : ACTIVE REPAIR TIME SRU"S                          A,O
450.      ASDAU   : T&SE,COMMON,COST/SITE,DEP-LEVEL                   S
250.      ASIAU   : T&SE,COMMON,COST/SITE,INT-LEVEL                   S
50.       ASOAL   : T&SE,COMMON,COST/SITE,ORG-LEVEL                   S
.05       ATTDL   : TECHNICIAN,ATTRITION RATE,DEP-LEVEL               S,A
.15       ATTIL   : TECHNICIAN,ATTRITION RATE,INT-LEVEL               S,A
.2        ATTOL   : TECHNICIAN,ATTRITION RATE,ORG-LEVEL               S,A
100.      AVDID   : DISTANCE,MILES,INT-DEP-LEVEL,ROUND TRIP           S
100.      AVDOD   : DISTANCE,MILES,ORG-DEP-LEVEL,ROUND TRIP           S
30.       AVDOI   : DISTANCE,MILES,ORG-INT-LEVEL,ROUND TRIP           S
1680.     CDDR    : DOCUMENTATION COST/SITE,DEP-LEVEL                 S,A
900.      CDIR    : DOCUMENTATION COST/SITE,INT-LEVEL                 S,A
.006      CDNL    : CONDEMNATION RATE,LRU REPAIR                      S,A
```

.02	CONS	: CONDEMNATION RATE,SRU REPAIR	S,A
50.	CDOR	: DOCUMENTATION COST/SITE,ORG-LEVEL	S,A
3075.	CL1	: UNIT COST,LRU1	S,A,C
4705.	CL2	: UNIT COST,LRU2	S,A,C
4160.	CL3	: UNIT COST,LRU3	S,A,C
3040.	CL4	: UNIT COST,LRU4	S,A,C
10670.	CL5	: UNIT COST,LRU5	S,A,C
11605.	CL6	: UNIT COST,LRU6	S,A,C
.3	CMOT	: TRANSPORTATION,COST/MILE	S
300.	CPSL1	: T&SE,PECULIAR,LRU1,UNIT COST	S,A
300.	CPSL2	: T&SE,PECULIAR,LRU2,UNIT COST	S,A
300.	CPSL3	: T&SE,PECULIAR,LRU3,UNIT COST	S,A
300.	CPSL4	: T&SE,PECULIAR,LRU4,UNIT COST	S,A
320.	CPSL5	: T&SE,PECULIAR,LRU5,UNIT COST	S,A
330.	CPSL6	: T&SE,PECULIAR,LRU6,UNIT COST	S,A
3180.	CPSS1	: T&SE,PECULIAR,SRU1,UNIT COST	S,A
3180.	CPSS2	: T&SE,PECULIAR,SRU2,UNIT COST	S,A
3180.	CPSS3	: T&SE,PECULIAR,SRU3,UNIT COST	S,A
3180.	CPSS4	: T&SE,PECULIAR,SRU4,UNIT COST	S,A
3180.	CPSS5	: T&SE,PECULIAR,SRU5,UNIT COST	S,A
3180.	CPSS6	: T&SE,PECULIAR,SRU6,UNIT COST	S,A
3180.	CPSS7	: T&SE,PECULIAR,SRU7,UNIT COST	S,A
3180.	CPSS8	: T&SE,PECULIAR,SRU8,UNIT COST	S,A
3180.	CPSS9	: T&SE,PECULIAR,SRU9,UNIT COST	S,A
3180.	CPSS10	: T&SE,PECULIAR,SRU10,UNIT COST	S,A
3180.	CPSS11	: T&SE,PECULIAR,SRU11,UNIT COST	S,A
1020.	CS1	: UNIT COST,SRU1	S,A,C
325.	CS2	: UNIT COST,SRU2	S,A,C

```
485.      CS3      : UNIT COST,SRU3                              S,A,C
1770.     CS4      : UNIT COST,SRU4                              S,A,C
960.      CS5      : UNIT COST,SRU5                              S,A,C
2105.     CS6      : UNIT COST,SRU6                              S,A,C
1005.     CS7      : UNIT COST,SRU7                              S,A,C
1575.     CS8      : UNIT COST,SRU8                              S,A,C
740.      CS9      : UNIT COST,SRU9                              S,A,C
890.      CS10     : UNIT COST,SRU10                             S,A,C
1345.     CS11     : UNIT COST,SRU11                             S,A,C
3.        DISRT    : DISCOUNT RATE,%                             S,A
40.       ENTC     : INVENTORY ENTERING COST                     S,A
.11       FACIN    : T&SE,PECULIAR,FRACTION,ANNUAL COST/INV      S,A
20.       FSAC     : FIELD SUPPLY ADMIN. COST($/ITEM/SITE/YR)    A
50.       HOLC     : INVENTORY HOLDING COST                      S,A
1.5       ISC      : INVENTORY STORAGE COST($/SQ.FT/YEAR)        A
6.        MLRUS    : NUMBER OF DIFFERENT LRU'S                   S,A,C
.003      MRLRU    : MATERIAL RATE LRU"S(FRACTION OF U.C)        A
.03       MRSRU    : MATERIAL RATE SRU"S(FRACTION OF U.C)        A
11.       MSRUS    : NUMBER OF DIFFERENT SRU'S                   S,A,C
1.        ND       : NUMBER OF DEP-LEVEL SITES                   S,A,C
2.        NI       : NUMBER OF INT-LEVEL SITES                   S,A,C
3.        NLRU1    : NUMBER OF LRU1/SYSTEM                       S,A,C
6.        NLRU2    : NUMBER OF LRU2/SYSTEM                       S,A,C
2.        NLRU3    : NUMBER OF LRU3/SYSTEM                       S,A,C
7.        NLRU4    : NUMBER OF LRU4/SYSTEM                       S,A,C
2.        NLRU5    : NUMBER OF LRU5/SYSTEM                       S,A,C
1.        NLRU6    : NUMBER OF LRU6/SYSTEM                       S,A,C
```

6.	NMTD	: # OF TRAINEE/DEPOT SITE,INITIAL	S,A
4.	NMTI	: # OF TRAINEE/INTERM. SITE,INITIAL	S,A
4.	NMTO	: # OF TRAINEE/OPERATIONAL SITE,INITIAL	S,A
198.	NPRT	: NUMBER OF CONSUMABLES IN INVENTORY	S,A
24.	NS	: NUMBER OF OPERATIONAL SITES	S,A,C
13.	NSRU1	: NUMBER OF SRU1/SYSTEM	S,A,C
12.	NSRU2	: NUMBER OF SRU2/SYSTEM	S,A,C
3.	NSRU3	: NUMBER OF SRU3/SYSTEM	S,A,C
12.	NSRU4	: NUMBER OF SRU4/SYSTEM	S,A,C
4.	NSRU5	: NUMBER OF SRU5/SYSTEM	S,A,C
8.	NSRU6	: NUMBER OF SRU6/SYSTEM	S,A,C
2.	NSRU7	: NUMBER OF SRU7/SYSTEM	S,A,C
4.	NSRU8	: NUMBER OF SRU8/SYSTEM	S,A,C
2.	NSRU9	: NUMBER OF SRU9/SYSTEM	S,A,C
1.	NSRU10	: NUMBER OF SRU10/SYSTEM	S,A,C
3.	NSRU11	: NUMBER OF SRU11/SYSTEM	S,A,C
15.	NY	: LIFE CYCLE PERIOD,YEARS	S,A
2.	PC	: PACKING COST	A
12300.	PCIL1	: INITIAL PROVISIONING COST,LRU1 (OPUS)	S
37640.	PCIL2	: INITIAL PROVISIONING COST,LRU2 (OPUS)	S
12480.	PCIL3	: INITIAL PROVISIONING COST,LRU3 (OPUS)	S
15200.	PCIL4	: INITIAL PROVISIONING COST,LRU4 (OPUS)	S
53350.	PCIL5	: INITIAL PROVISIONING COST,LRU5 (OPUS)	S
278520.	PCIL6	: INITIAL PROVISIONING COST,LRU6 (OPUS)	S
15300.	PCIS1	: INITIAL PROVISIONING COST,SRU1 (OPUS)	S
2275.	PCIS2	: INITIAL PROVISIONING COST,SRU2 (OPUS)	S
1940.	PCIS3	: INITIAL PROVISIONING COST,SRU3 (OPUS)	S
42480.	PCIS4	: INITIAL PROVISIONING COST,SRU4 (OPUS)	S

3840.	FCIS5	: INITIAL PROVISIONING COST,SRU5 (OPUS)	S
27365.	FCIS6	: INITIAL PROVISIONING COST,SRU6 (OPUS)	S
3015.	FCIS7	: INITIAL PROVISIONING COST,SRU7 (OPUS)	S
9450.	PCIS8	: INITIAL PROVISIONING COST,SRU8 (OPUS)	S
2960.	FCIS9	: INITIAL PROVISIONING COST,SRU9 (OPUS)	S
1780.	FCIS10	: INITIAL PROVISIONING COST,SRU10 (OPUS)	S
8070.	PCIS11	: INITIAL PROVISIONING COST,SRU11 (OPUS)	S
52.	PLT	: PROCUREMENT LEAD TIME(WEEKS)	A,O
42.	FPL1	: NUMBER OF PECULIAR PARTS,LRU1	S,A
15.	FPL2	: NUMBER OF PECULIAR PARTS,LRU2	S,A
17.	PPL3	: NUMBER OF PECULIAR PARTS,LRU3	S,A
0.	FPL4	: NUMBER OF PECULIAR PARTS,LRU4	S,A
42.	FPL5	: NUMBER OF PECULIAR PARTS,LRU5	S,A
36.	FPL6	: NUMBER OF PECULIAR PARTS,LRU6	S,A
22.	FPS1	: NUMBER OF PECULIAR PARTS,SRU1	S,A
31.	FPS2	: NUMBER OF PECULIAR PARTS,SRU2	S,A
11.	FPS3	: NUMBER OF PECULIAR PARTS,SRU3	S,A
15.	FPS4	: NUMBER OF PECULIAR PARTS,SRU4	S,A
17.	FPS5	: NUMBER OF PECULIAR PARTS,SRU5	S,A
24.	PPS6	: NUMBER OF PECULIAR PARTS,SRU6	S,A
18.	FPS7	: NUMBER OF PECULIAR PARTS,SRU7	S,A
24.	PPS8	: NUMBER OF PECULIAR PARTS,SRU8	S,A
10.	FPS9	: NUMBER OF PECULIAR PARTS,SRU9	S,A
8.	FPS10	: NUMBER OF PECULIAR PARTS,SRU10	S,A
18.	FPS11	: NUMBER OF PECULIAR PARTS,SRU11	S,A
.4	PRLTC	: RATIO,DISCARD TC REPAIR MANHOURS	S
25.	RCOC	: REPAIR CYCLE,ORG-DEP(DAYS)	A,O

6.	RCOI	: REPAIR CYCLE,ORG-INT(DAYS)	A,O
90.	RDSC	: REQUIRED DAYS OF STOCK,DISCARD,ORG-LEV.	A
37.	ROID	: REPAIR CYCLE,ORG-INT-DEP(DAYS)	A,O
15.5	RLDL	: MANHOUR RATE,DEP-LEVEL	S,A
10.	RLIL	: MANHOUR RATE,INT-LEVEL	S,A
10.	RLOL	: MANHOUR RATE,ORG-LEVEL	S,A
15000C.	SCS	: UNIT COST,SYSTEM	S,O
6.6	SL	: SAFETY LEVEL(WEEKS)	A
.1	SPMAIN	: SPACE,MAINT. OF,FRACT. ANN./INV.COST	S
1.	S1	: MTBF,MULTIPLICATION FACTOR	S
1.	S2	: CORR.MAINT-TIME,MULTIPLICATION FACTOR	S
1.	S3	: UNIT COST,MULTIPLICATION FACTOR	S
3.	TCAD	: AVERAGE MANHOURS/CORR.MAINT.ACT.DEP-LEV	S
3.	TCAI	: AVERAGE MANHOURS/CORR.MAINT.ACT.INT-LEV	S
2.2	TCAO	: AVERAGE MANHOURS/CORR.MAINT.ACT.ORG-LEV	S
1500.	TCTD	: COST/TRAINEE,COURSE,DEP-LEVEL	S,A
750.	TCTI	: COST/TRAINEE,COURSE,INT-LEVEL	S,A
500.	TCTO	: COST/TRAINEE,COURSE,ORG-LEVEL	S,A
8.	TPAD	: AVERAGE TIME/PREV.MAINT.ACT.DEP-LEVEL	S
5.	TPAI	: AVERAGE TIME/PREV.MAINT.ACT.INT-LEVEL	S
1.	TPAO	: AVERAGE TIME/PREV.MAINT.ACT.ORG-LEVEL	S
.1	TCOI	: TRANSPORTATION COST,ORG-INT,($/LB)	A
.25	TCOD	: TRANSPORTATION COST,ORG-DEP,($/LB)	A
.2	TCID	: TRANSPORTATION COST,INT-DEP,($/LB)	A
.5	TEWS	: T&SE AND WORK SPACE COST($/SQ.FT/YEAR)	A
.1	UDSK	: DOCUMENTATION,FRACTION,ANN./INV. COST	S
1.2	VLRUD	: VERIFY TIME,DISCARD,LRU"S,DEP-LEVEL	A
1.2	VLRUI	: VERIFY TIME,DISCARD,LRU"S,INT-LEVEL	A

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1.3     VLRUC    : VERIFY TIME,DISCARD,LRU"S,ORG-LEVEL   A
2.2     VLRU1    : VOLUME OF LRU1(SQ.FT)                 A
2.4     VLRU2    : VOLUME OF LRU2(SQ.FT)                 A
2.2     VLRU3    : VOLUME OF LRU3(SQ.FT)                 A
2.4     VLRU4    : VOLUME OF LRU4(SQ.FT)                 A
2.      VLRU5    : VOLUME OF LRU5(SQ.FT)                 A
1.4     VLRU6    : VOLUME OF LRU6(SQ.FT)                 A
1.2     VSRUC    : VERIFY TIME,DISCARD,SRU"S,DEP-LEVEL   A
.2      VSRU1    : VOLUME OF SRU1(SQ.FT)                 A
.4      VSRU2    : VOLUME OF SRU2(SQ.FT)                 A
.4      VSRU3    : VOLUME OF SRU3(SQ.FT)                 A
1.1     VSRU4    : VOLUME OF SRU4(SQ.FT)                 A
.9      VSRU5    : VOLUME OF SRU5(SQ.FT)                 A
.1      VSRU6    : VOLUME OF SRU6(SQ.FT)                 A
1.5     VSRU7    : VOLUME OF SRU7(SQ.FT)                 A
.2      VSRU8    : VOLUME OF SRU8(SQ.FT)                 A
.1      VSRU9    : VOLUME OF SRU9(SQ.FT)                 A
.7      VSRU10   : VOLUME OF SRU10(SQ.FT)                A
.1      VSRU11   : VOLUME OF SRU11(SQ.FT)                A
35.     WLRU1    : WEIGHT OF LRU1(LBS.)                  A
50.     WLRU2    : WEIGHT OF LRU2(LBS.)                  A
60.     WLRU3    : WEIGHT OF LRU3(LBS.)                  A
35.     WLRU4    : WEIGHT OF LRU4(LBS.)                  A
70.     WLRU5    : WEIGHT OF LRU5(LBS.)                  A
90.     WLRU6    : WEIGHT OF LRU6(LBS.)                  A
5.      WSRU1    : WEIGHT OF SRU1(LBS.)                  A
5.      WSRU2    : WEIGHT OF SRU2(LBS.)                  A
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5.       WSRU3    : WEIGHT OF SRU3(LBS.)           A
7.       WSRU4    : WEIGHT OF SRU4(LBS.)           A
6.       WSRU5    : WEIGHT OF SRU5(LBS.)           A
8.       WSRU6    : WEIGHT OF SRU6(LBS.)           A
8.       WSRU7    : WEIGHT OF SRU7(LBS.)           A
8.       WSRU8    : WEIGHT OF SRU8(LBS.)           A
6.       WSRU9    : WEIGHT OF SRU9(LBS.)           A
9.       WSRU10   : WEIGHT OF SRU10(LBS.)          A
12.      WSRU11   : WEIGHT OF SRU11(LBS.)          A
9250.    XMFL1    : MTBF,LRU1                      S,A,C
4775.    XMFL2    : MTBF,LRU2                      S,A,C
8000.    XMFL3    : MTBF,LRU3                      S,A,C
13900.   XMFL4    : MTBF,LRU4                      S,A,C
3200.    XMFL5    : MTBF,LRU5                      S,A,C
2100.    XMFL6    : MTBF,LRU6                      S,A,C
24150.   XMFS1    : MTBF,SRU1                      S,A,C
83333.   XMFS2    : MTBF,SRU2                      S,A,C
53750.   XMFS3    : MTBF,SRU3                      S,A,C
11900.   XMFS4    : MTBF,SRU4                      S,A,C
45400.   XMFS5    : MTBF,SRU5                      S,A,C
14700.   XMFS6    : MTBF,SRU6                      S,A,C
50000.   XMFS7    : MTBF,SRU7                      S,A,C
22750.   XMFS8    : MTBF,SRU8                      S,A,C
29400.   XMFS9    : MTBF,SRU9                      S,A,C
41500.   XMFS10   : MTBF,SRU10                     S,A,C
17850.   XMFS11   : MTBF,SRU11                     S,A,C

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F.3. EXAMPLES OF AIR OUTPUT

Six examples of AIR output are included (the version called "USER SPECIFIED ALTERNATIVE 2" is the AIR version principally explored in Chapter VI):

a) Table F-2 illustrates the LSC of the various eight LOR alternatives for WRA's (LRU's) and SRA's (SRU's).

b) Table F-3 illustrates the LSC breakdown and percent of LSC of each cost category for WRA's and SRA's.

c) Table F-4 is an example of per site inventories of WRA's and SRA's. WRA's 100 through 600 correspond to LRU's 1 through 6 and SRA's 110 through 692 relate sequentially to SRU's 1 through 11 in the example (SRA's 110, 120, and 130 are SRU1. SRA's 560 and 660 are SRU6). Inventory sites include 24 system sites (each including the inventory quantities as described for ORG 22), two intermediate level sites (PIMA1 and PIMA2), a depot level site (DEPOT), and a central stock (SYSTEM STOCK).

RP is the rotatable pool inventory, AQ is the attrition quantity, and SC is the scrap quantity.

d) Table F-5 illustrates a sensitivity analysis of LSC vs. MTBF of the eight level of repair (LOR) alternatives (the basic MTBF is denoted by "100%").

e) Table F-6 is an example of an item summary report of LSC for four of the LOR alternatives.

f) Table F-7 illustrates a sensitivity analysis of "USER SPECIFIED ALTERNATIVE 2" of LSC for various MTBF percentages.

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Table F-2. TOTAL LIFE CYCLE LOGISTICS COST

	ALL WRA'S DISCARD	ALL WRA'S LOCAL ALL SRA'S DISCARD	ALL WRA'S LOCAL ALL SRA'S LOCAL SUB-SRA'S OPTIMIZED	ALL WRA'S LOCAL ALL SRA'S PIMA SUB-SRA'S OPTIMIZED
WRA LEVEL	55953072.0	69347184.0	69347184.0	69347184.0
SRA LEVEL	.0	13187315.0	17793136.0	4829971.0
SUB-SRA LEVEL	.0	.0	.0	.0
TOTAL	55953072.0	82534496.0	87140320.0	74177152.0

	ALL WRA'S LOCAL ALL SRA'S DEPOT SUB-SRA'S OPTIMIZED	LEAST COST ALTERNATIVE	USER SPECIFIED ALTERNATIVE 1	USER SPECIFIED ALTERNATIVE 2
WRA LEVEL	69347184.0	2473248.0	2423159.0	2423159.0
SRA LEVEL	3591712.0	1409356.0	1513857.0	1569029.0
SUB-SRA LEVEL	.0	.0	.0	.0
TOTAL	72938896.0	3882604.0	3937016.0	3992188.0

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Table F-3. COST BREAKDOWN AND PERCENT OF TOTAL LIFE CYCLE LOGISTICS COSTS

USER SPECIFIED
ALTERNATIVE # 2

	WRA		SRA		SUB-SRA		TOTAL	
	$	%	$	%	$	%	$	%
SUPPORT EQUIP.	49050.0	2.02	105000.0	6.69	0.	0.	154050.0	3.86
SUPPORT OF SE	63317.6	2.61	135542.1	8.64	0.	0.	198859.7	4.98
INVENTORY	875300.0	36.12	26570.0	1.69	0.	0.	901930.0	22.59
INV. ADMIN.	41545.2	1.71	251868.4	16.05	0.	0.	293413.6	7.35
SE SPACE	35216.9	1.45	5013.9	.32	0.	0.	40230.8	1.01
INV. STORAGE	4824.1	.20	195.2	.01	0.	0.	5019.3	.13
REPAIR SPACE	.0	0.	0.	0.	0.	0.	0.	0.
LABOR	417038.2	17.21	280282.5	17.86	0.	0.	697320.7	17.47
MATERIAL	164801.7	6.80	183898.8	11.72	0.	0.	348700.5	8.73
TRANSPORTATION	266388.2	10.99	40477.1	2.58	0.	0.	306865.2	7.69
REPAIR SCRAP	331592.8	13.68	215572.9	13.74	0.	0.	547165.7	13.71
TRAINING	172975.6	7.14	322930.1	20.58	0.	0.	495905.7	12.42
DOCUMENTATION	1050.0	.04	1680.0	.11	0.	0.	2730.0	.07
TOTAL	2423159.0	100.00	1569029.0	100.00	0.	0.	3992188.0	100.00

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Table F-4. PER SITE INVENTORY VALUES

ALTERNATIVE - U-S-E-R S-P-E-C-I-F-I-E-D # 2

ITEM	INPUT I.D.	SYSTEM STOCK	CRG22 RP	CRG22 AQ	CRG22 SC	CRG23 RP	CRG23 AQ	CRG23 SC	CRG24 RP	CRG24 AQ	CRG24 SC	PIMA1 RP	PIMA1 AQ	PIMA1 SC	PIMA2 RP	PIMA2 AQ	PIMA2 SC	DEPOT RP	DEPOT AQ	DEPOT SC
WRA	100	1	0	0	.0	0	0	.0	0	0	.0	0	0	.3	0	0	.1	0	0	.0
SRA	110	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.5
SRA	120	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.6
SRA	130	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.2
WRA	200	2	0	2	.0	0	2	.0	0	2	.0	0	0	1.0	0	0	.5	0	0	.0
SRA	210	2	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	1.0
SRA	240	5	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	4.2
WRA	300	1	0	0	.0	0	0	.0	0	0	.0	0	0	.2	0	0	.1	0	0	.0
SRA	310	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.7
SRA	350	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.4
WRA	400	1	0	1	.0	0	1	.0	0	1	.0	0	0	.4	0	0	.2	0	0	.0
WRA	500	1	0	1	.0	0	1	.0	0	1	.0	0	0	.5	0	0	.3	0	0	.0
SRA	560	2	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	1.7
SRA	570	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.2
SRA	580	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.7
WRA	600	1	0	1	.0	0	1	.0	0	1	.0	0	0	.4	0	0	.2	0	0	.0
SRA	660	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.6
SRA	690	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.3
SRA	691	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.1
SRA	692	1	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.0	0	0	.7

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Table F-5. SENSITIVITY ANALYSIS - GROUP 1
TOTAL COST ($1000) BY ALTERNATIVE (WITHOUT REOPTIMIZATION)

8. MTBF

ALT	WRA	SRA	SUB-SRA	25% 1	36% 2	46% 3	57% 4	68% 5	79% 6	89% 7	100% 8
1	ALL DISCARD			223065	156219	120227	97730	82338	71144	62637	55953
2	ALL LOCAL	ALL DISCARD		319579	224783	173609	141632	119894	104108	92053	82535
3	ALL LOCAL	ALL LOCAL	OPTIMIZED	331357	233767	180951	148027	125711	109434	96955	87140
4	ALL LOCAL	ALL PIMA	OPTIMIZED	284598	200513	155032	126607	107326	93332	82657	74177
5	ALL LOCAL	ALL DEPOT	OPTIMIZED	279837	197164	152437	124493	105528	91771	81316	72939
6	OPTIMIZED	OPTIMIZED	OPTIMIZED	12185**	8614 *	6931 *	5951 *	5126 *	4510 *	4155 *	3883 *
7	U-S-E-R	S-P-E-C-I-F-I-E-D # 1		12185**	8633**	6960**	5986**	5169**	4560**	4247**	3937**
8	U-S-E-R	S-P-E-C-I-F-I-E-D # 2		12149 *	8632**	6979**	6018**	5210**	4606**	4255**	3992**

* DENOTES LOWEST COST ALTERNATIVE
** DENOTES ALTERNATIVES WITHIN 20 PERCENT OF THE LOWEST

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Table F-6. ITEM SUMMARY REPORT WITH MAINTENANCE SCHEME

ITEM	INPUT I.D. CODE	ALL WRA'S LOCAL ALL SRA'S DEPOT SUB-SRA'S OPTIMIZED	LOR ALT	LEAST COST ALTERNATIVE	LOR ALT	USER SPECIFIED ALTERNATIVE # 1	LOR ALT	USER SPECIFIED ALTERNATIVE # 2	LOR ALT
WRA AGG.		.0		.0		.0		.0	
WRA	100	3276319.0	I	161700.7	D *	139694.2	P	139694.2	P
SRA AGG.		.0		.0		.0		.0	
SRA	110	227635.3	D	65966.5	D *	91445.2	D *	91445.2	D
SRA	120	227069.1	D	64551.2	D *	82783.6	P *	91023.1	D
SRA	130	195377.8	D	38696.0	D *	47614.0	P *	61642.1	D
WRA	200	18735328.0	I	672774.9	P *	672774.9	P	672774.9	P
SRA AGG.		.0		.0		.0		.0	
SRA	210	260464.2	D	121546.8	D *	121546.8	D *	121546.8	D
SRA	240	475624.7	D	273509.7	D *	273509.7	D *	273509.7	D
WRA	300	3411314.0	I	161628.8	D *	133546.8	P	133546.8	P
SRA AGG.		.0		.0		.0		.0	
SRA	310	237637.1	D	74067.5	D *	101137.9	D *	101137.9	D
SRA	350	213265.4	D	53828.3	D *	78631.4	D *	78631.4	D
WRA	400	4938267.0	I	257368.8	P *	257368.8	P	257368.8	P
WRA	500	21196336.0	I	623871.2	P *	623871.2	P	623871.2	P
SRA AGG.		.0		.0		.0		.0	
SRA	560	413653.2	D	219401.7	D *	219401.7	D *	219401.7	D
SRA	570	202183.9	D	59827.1	P *	59827.1	P *	68831.5	D
SRA	580	255815.4	D	118700.2	D *	118700.2	D *	118700.2	D
WRA	600	17789632.0	I	595904.1	P *	595904.1	P	595904.1	P
SRA AGG.		.0		.0		.0		.0	
SRA	660	251970.8	D	115899.5	D *	115899.5	D *	115899.5	D
SRA	690	159211.3	D	56049.3	P *	56049.3	P *	65132.5	D
SRA	691	188394.6	D	40658.3	P *	40658.3	P *	55475.6	D
SRA	692	243613.7	D	106654.6	D *	106654.6	D *	106654.6	D
TOTAL		72938896.0		3882604.0		3937016.0		3992188.0	

* INDICATES OPTIMIZED LOR DECISION

** DESIGNATED LOR CODE OVERRIDDEN BY HIGHER INCENTURE LEVEL LOR DECISION

I - IMA(LOCAL)
P - PIMA
D - DEPOT
X - DISCARD

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Table F-7. SENSITIVITY ANALYSIS - GROUP 1
COST BREAKDOWN($1000) (WITH REOPTIMIZATION)

ALTERNATIVE: USER SPECIFIED # 2

8. MTBF		25%		36%		46%		57%		68%		75%		89%		100%	
		1		2		3		4		5		6		7		8	
		$	%	$	%	$	%	$	%	$	%	$	%	$	%	$	%
SUPPORT EQUIP.	WRA	49	.4	49	.6	49	.7	49	.8	49	.9	49	1.1	49	1.1	49	1.2
	SRA	105	.9	105	1.2	105	1.5	105	1.7	105	2.0	105	2.3	105	2.4	105	2.6
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	154	1.3	154	1.8	154	2.2	154	2.6	154	3.0	154	3.3	154	3.6	154	3.9
SUPPORT OF SE	WRA	63	.5	63	.7	63	.9	63	1.1	63	1.2	63	1.4	63	1.5	63	1.6
	SRA	136	1.1	136	1.6	136	1.9	136	2.3	136	2.6	136	2.9	136	3.2	136	3.4
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	199	1.6	199	2.3	199	2.8	199	3.3	199	3.8	199	4.3	199	4.6	199	5.0
INVENTORY	WRA	3255	26.8	2048	23.7	1639	23.5	1453	24.1	1180	22.7	965	20.9	949	22.1	875	21.9
	SRA	88	.7	65	.8	52	.7	46	.8	36	.7	32	.7	30	.7	27	.7
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	3343	27.5	2114	24.5	1691	24.2	1499	24.9	1216	23.3	997	21.6	980	22.8	902	22.6
INV. ADMIN.	WRA	42	.3	42	.5	42	.6	42	.7	42	.8	42	.9	42	1.0	42	1.0
	SRA	252	2.1	252	2.9	252	3.6	252	4.2	252	4.8	252	5.5	252	5.9	252	6.3
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	293	2.4	293	3.4	293	4.2	293	4.9	293	5.6	293	6.4	293	6.8	293	7.3
SE SPACE	WRA	35	.3	35	.4	35	.5	35	.6	35	.7	35	.8	35	.8	35	.9
	SRA	5	.0	5	.1	5	.1	5	.1	5	.1	5	.1	5	.1	5	.1
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	40	.3	40	.5	40	.6	40	.7	40	.8	40	.9	40	.9	40	1.0
INV. STORAGE	WRA	19	.2	13	.1	11	.2	9	.1	8	.2	6	.1	6	.1	5	.1
	SRA	1	.0	0	.0	0	.0	0	.0	0	.0	0	.0	0	.0	0	.0
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	20	.2	13	.2	11	.2	9	.2	8	.2	6	.1	6	.1	5	.1
REPAIR SPACE	WRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	SRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.

LEVEL OF REPAIR ANALYSIS- MOD 03

U.S. NAVAL WEAPONS ENGINEERING SUPPORT ACTIVITY
WASHINGTON NAVY YARD, WASHINGTON, D.C.

SENSITIVITY ANALYSIS - GROUP 1
COST BREAKDOWN($1000) (WITH REOPTIMIZATION)

ALTERNATIVE: USER SPECIFIED # 2

8. MTBF		25%		36%		46%		57%		68%		79%		89%		100%	
		1		2		3		4		5		6		7		8	
		$	%	$	%	$	%	$	%	$	%	$	%	$	%	$	%
LABOR	WRA	1668	13.7	1168	13.5	898	12.9	730	12.1	615	11.8	531	11.5	467	10.9	417	10.4
	SRA	1121	9.2	785	9.1	604	8.6	490	8.1	413	7.9	357	7.7	314	7.3	280	7.0
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	2789	23.0	1952	22.6	1502	21.5	1220	20.3	1028	19.7	887	19.3	781	18.2	697	17.5
MATERIAL	WRA	659	5.4	461	5.3	355	5.1	288	4.8	243	4.7	210	4.6	185	4.3	165	4.1
	SRA	736	6.1	515	6.0	396	5.7	322	5.3	271	5.2	234	5.1	206	4.8	184	4.6
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	1395	11.5	976	11.3	751	10.8	610	10.1	514	9.9	444	9.6	391	9.1	349	8.7
TRANSPORTATION	WRA	1066	8.8	746	8.6	574	8.2	466	7.7	393	7.5	339	7.4	298	6.9	266	6.7
	SRA	162	1.3	113	1.3	87	1.2	71	1.2	60	1.1	52	1.1	45	1.1	40	1.0
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	1227	10.1	859	10.0	661	9.5	537	8.9	452	8.7	391	8.5	344	8.0	307	7.7
REPAIR SCRAP	WRA	1326	10.9	928	10.8	714	10.2	580	9.6	489	9.4	422	9.2	371	8.6	332	8.3
	SRA	862	7.1	604	7.0	464	6.7	377	6.3	318	6.1	274	6.0	241	5.6	216	5.4
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	2189	18.0	1532	17.7	1179	16.9	958	15.9	806	15.5	696	15.1	613	14.3	547	13.7
TRAINING	WRA	173	1.4	173	2.0	173	2.5	173	2.9	173	3.3	173	3.8	173	4.0	173	4.3
	SRA	323	2.7	323	3.7	323	4.6	323	5.4	323	6.2	323	7.0	323	7.5	323	8.1
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	496	4.1	496	5.7	496	7.1	496	8.2	496	9.5	496	10.8	496	11.5	496	12.4
DOCUMENTATION	WRA	1	.0	1	.0	1	.0	1	.0	1	.0	1	.0	1	.0	1	.0
	SRA	2	.0	2	.0	2	.0	2	.0	2	.0	2	.0	2	.0	2	.0
	XRA	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.	0	0.
	TOTAL	3	.0	3	.0	3	.0	3	.0	3	.1	3	.1	3	.1	3	.1
	TOTAL	12149		8632		6979		6018		5210		4606		4299		3992	

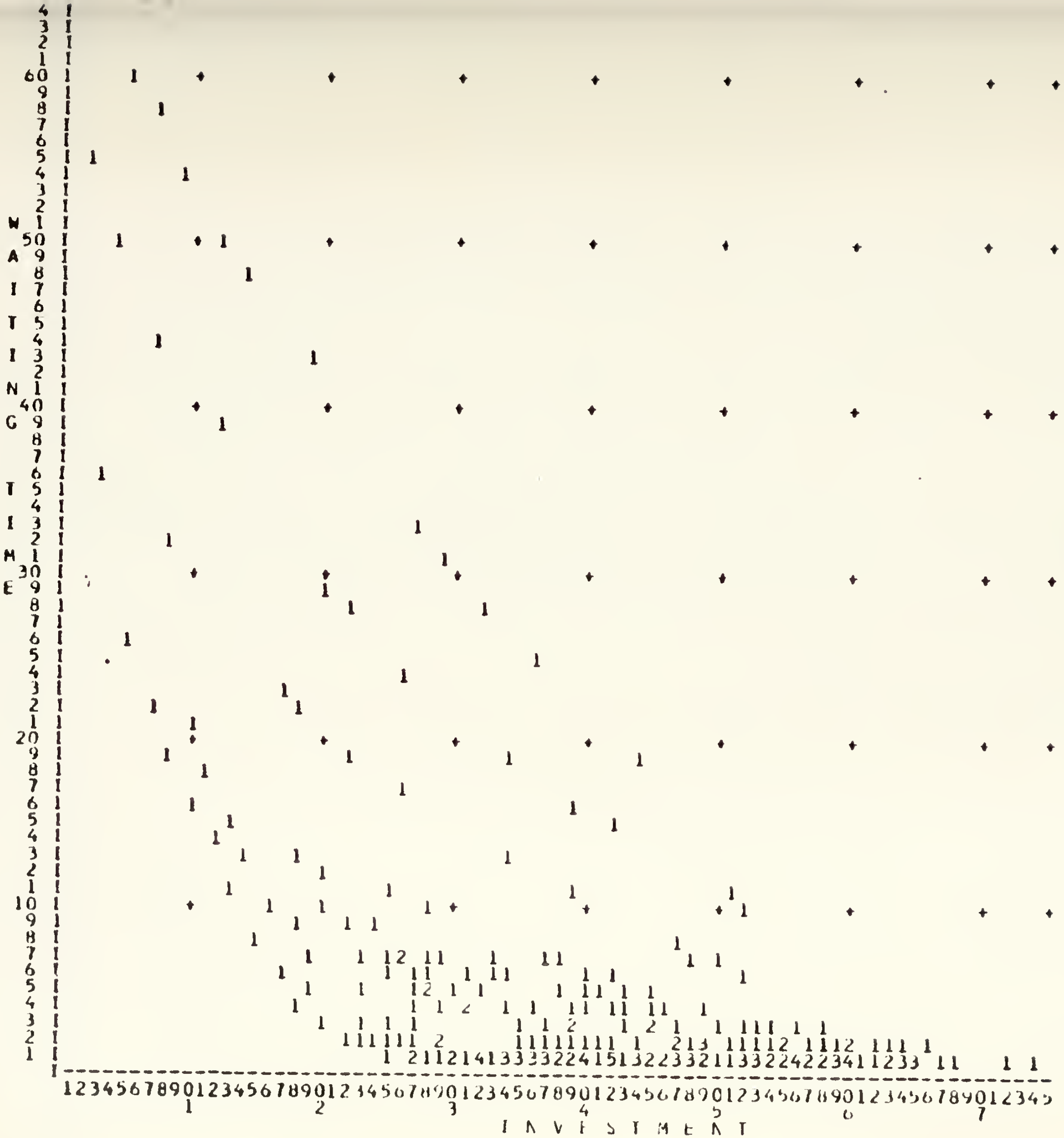
F.4. EXAMPLES OF OPUS-VII OUTPUT

Six examples of OPUS-VII output are included:

a) Figure F-1 illustrates cost-effectiveness (C-E) curves for waiting time as a function of the investment in initial procurement of spares (Section C.4).

b) Figure F-2 illustrates the optimal envelope of the C-E curves of Figure F-1.

c) Tables F-8 through F-11 demonstrate inventory data and measure of effectiveness values for four points on Figure F-2.



ALL POINTS

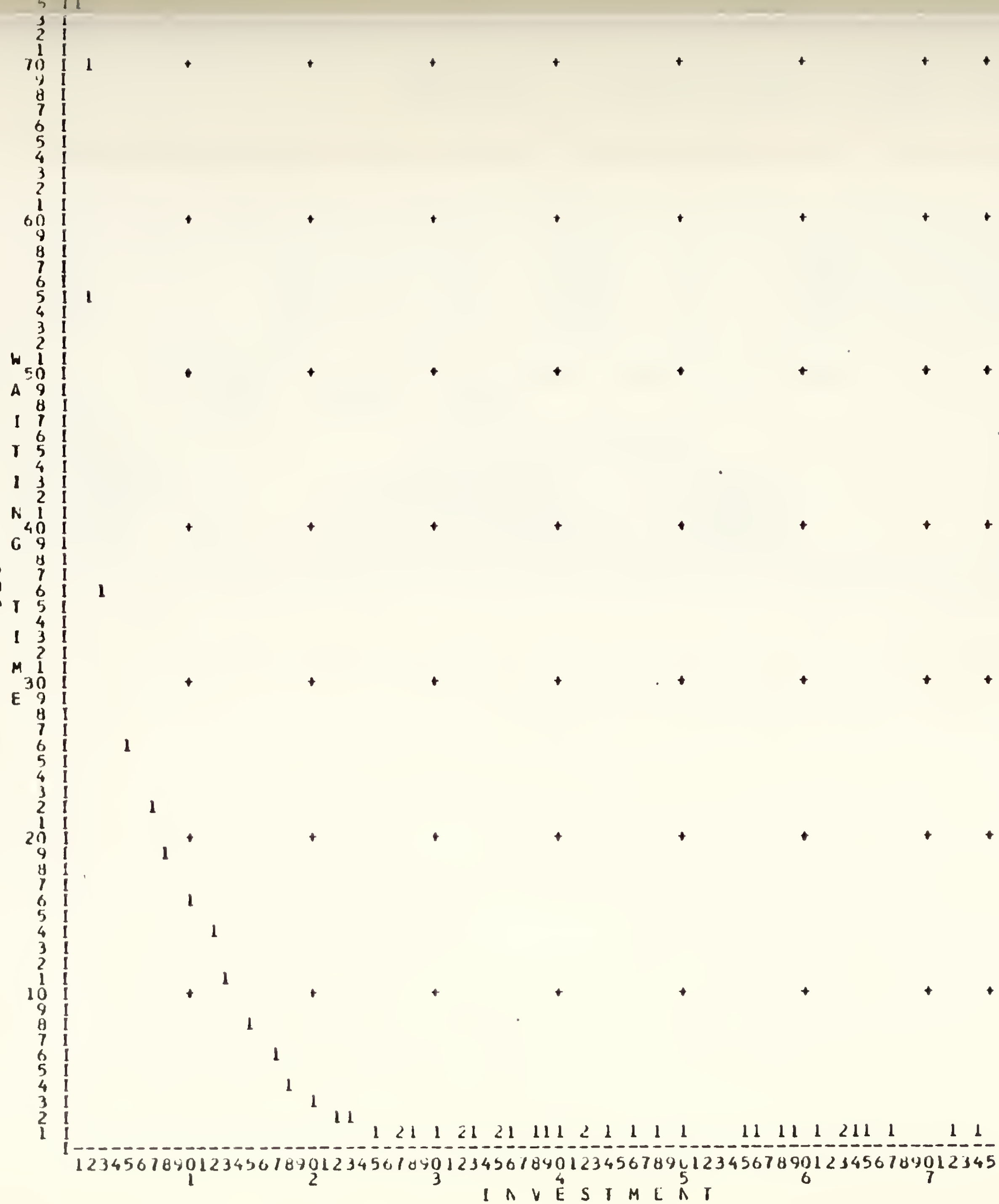
SCALE OF X-AXIS

INVESTMENT
MINIMUM = 0.0
STEP LENGTH= 0.21103E+05
MAXIMUM = 0.15616E+07

SCALE OF Y-AXIS

WAITING TIME
MINIMUM = 0.16917E-02
STEP LENGTH= 0.12958E+02
MAXIMUM = 0.55891E+03

Figure F-1. C-E Curves for the Organizational Level




```
C/F-CURVE

SCALE OF X-AXIS
---------------

      INVESTMENT
MINIMUM     = C.0
STEP LENGTH= 0.21103E+05
MAXIMUM     = 0.15616E+07

SCALE OF Y-AXIS
---------------

      WAITING TIME
MINIMUM     = 0.16917E-02
STEP LENGTH= 0.12958E+02
MAXIMUM     = 0.55891E+03
```

Figure F-2. The Final C-E Curve (Organizational Level)

Table F-8. Inventory Data and MOE Values, Point #1

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**************************************************************************************************************************************

EXAMPLE NC.CC 111481    MOE=EXPECTED WAITING TIME                                                    POINT NC.  1

DENOM    TOTAL   INVESTM. DEPIN1IN2MN1MN2    DENOM    TOTAL    INVESTM. DEPIN1IN2MN1MN2    DENOM    TOTAL    INVESTM. DEPIN1IN2MN1MN2
 LRU 1     0        0.0   0  0  0  0  0       SRU 1     0         0.0   0  0  0  0  0       SRU 7     0         0.0   0  0  0  0  0
 LRU 2     0        0.0   0  0  0  0  0       SRU 2     0         0.0   0  0  0  0  0       SRU 8     0         0.0   0  0  0  0  0
 LRU 3     0        0.0   0  0  0  0  0       SRU 3     0         0.0   0  0  0  0  0       SRU 9     0         0.0   0  0  0  0  0
 LRU 4     0        0.0   0  0  0  0  0       SRU 4     0         0.0   0  0  0  0  0       SRU10     0         0.0   0  0  0  0  0
 LRU 5     0        0.0   0  0  0  0  0       SRU 5     0         0.0   0  0  0  0  0       SRU11     0         0.0   0  0  0  0  0
 LRU 6     0        0.0   0  0  0  0  0       SRU 6     0         0.0   0  0  0  0  0

            AVAILABILITY
            PER SYSTEM:     PER SYSTEM AND DEMAND GENERATING STATION
                               OR1        CR2
 SYSTEM 1     0.23251    0.23251    0.23251
TOTAL   :     0.23251

INVESTMENT                          MEASURE OF EFFECTIVENESS
----------                          ------------------------
TCT INVESTM.     =           0.0    AVAILIABILITY        =    0.23251
PERC F S S       =           0.0     N C R S             =   18.41963
PERC FIRST LEVEL=            0.0    WAITING TIME         =  950.91187
PERC LRU         =           0.0    RISK CF SHCRTAGE     =   1.000000
PERC SRU         =           0.0    RSK SFRTGE(1ST LVL)=     1.000000

**************************************************************************************************************************************
```

Table F-9. Inventory Data and MOE Values, Point #7

EXAMPLE NC.00 111481 MCE=EXPECTEC WAITING TIME POINT NC. 7

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
LRU 1	4	12300.0	0	2	2	0	0
LRU 2	8	37640.0	0	5	3	0	0
LRU 3	3	12480.0	0	2	1	0	0
LRU 4	5	15200.0	0	3	2	0	0
LRU 5	5	53350.0	0	3	2	0	0
LRU 6	24	278520.0	15	6	3	0	0

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
SRU 1	15	15300.0	10	3	2	0	0
SRU 2	7	2275.0	4	2	1	0	0
SRU 3	4	1540.0	2	1	1	0	0
SRU 4	24	42480.0	16	5	3	0	0
SRU 5	4	3840.0	2	1	1	0	0
SRU 6	13	27365.0	7	4	2	0	0

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
SRU 7	3	3015.0	1	1	1	0	0
SRU 8	6	9450.0	3	2	1	0	0
SRU 9	4	2960.0	2	1	1	0	0
SRU10	2	1780.0	1	1	0	0	0
SRU11	6	8070.0	3	2	1	0	0

	AVALIABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION OR1	CR2
SYSTEM 1	0.97465	0.97896	0.96605
TOTAL :	0.97465		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	527965.0	AVAILIABILITY =	0.97465
PERC E S S =	46.1	N O R S =	0.60829
PERC FIRST LEVEL=	0.0	WAITING TIME =	5.28426
PERC LRU =	77.6	RISK CF SHCRTAGE =	1.000000
PERC SRU =	22.4	RSK SHRTGE(1ST LVL)=	1.000000

Table F-10. Inventory Data and MOE Values, Point #12

EXAMPLE NO.OC 111481 MOE=EXPECTED WAITING TIME POINT NO. 12

DENOM	TOTAL	INVESTM.	DEP	NI1	IN2	MNI	MN2
LRU 1	29	89175.0	0	3	2	1	1
LRU 2	35	164675.0	0	7	4	1	1
LRU 3	13	54030.0	0	3	2	0	1
LRU 4	31	94240.0	0	4	3	1	1
LRU 5	7	74690.0	0	4	3	0	0
LRU 6	28	324940.0	18	6	4	0	0

DENOM	TOTAL	INVESTM.	DEP	NI1	IN2	MNI	MN2
SRU 1	15	15300.0	10	3	2	0	0
SRU 2	7	2275.0	4	2	1	0	0
SRU 3	4	1940.0	2	1	1	0	0
SRU 4	24	42480.0	16	5	3	0	0
SRU 5	4	3840.0	2	1	1	0	0
SRU 6	15	31575.0	7	5	3	0	0

DENOM	TOTAL	INVESTM.	DEP	NI1	IN2	MNI	MN2
SRU 7	3	3015.0	1	1	1	0	0
SRU 8	6	5450.0	3	2	1	0	0
SRU 9	4	2960.0	2	1	1	0	0
SRU10	3	2670.0	1	1	1	0	0
SRU11	6	8070.0	3	2	1	0	0

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION ORI	CH2
SYSTEM 1	0.98922	0.98911	0.98945
TOTAL :	0.98922		

INVESTMENT			MEASURE OF EFFECTIVENESS		
TOT INVESTM.	=	925375.0	AVAILIABILITY	=	0.98922
PERC E S S	=	30.1	N C H S	=	0.25870
PERC FIRST LEVEL	=	31.7	WAITING TIME	=	0.87302
PERC LRU	=	86.6	RISK OF SHORTAGE	=	0.369623
PERC SRU	=	13.4	RSK SHRTGE(1ST LVL)	=	0.369623

Table F-11. Inventory Data and MOE Values, Point #20

EXAMPLE NO.00 111481 MOE=EXPECTED WAITING TIME POINT NO. 20

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
LRU 1	31	95325.0	0	4	3	1	1
LRU 2	36	169330.0	0	7	5	1	1
LRU 3	29	120640.0	0	3	2	1	1
LRU 4	31	94240.0	0	4	3	1	1
LRU 5	31	330770.0	0	4	3	1	1
LRU 6	53	615065.0	21	5	3	1	1

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
SRU 1	17	17340.0	11	4	2	0	0
SRU 2	8	2600.0	5	2	1	0	0
SRU 3	4	1940.0	2	1	1	0	0
SRU 4	26	46020.0	18	5	3	0	0
SRU 5	5	4800.0	2	2	1	0	0
SRU 6	16	33680.0	9	4	3	0	0

DENOM	TOTAL	INVESTM.	DEP	IN1	IN2	MN1	MN2
SRU 7	3	3015.0	1	1	1	0	0
SRU 8	7	11025.0	4	2	1	0	0
SRU 9	5	3700.0	2	2	1	0	0
SRU10	3	2670.0	1	1	1	0	0
SRU11	7	9415.0	4	2	1	0	0

	AVAILABILITY PER SYSTEM:	PER SYSTEM AND DEMAND GENERATING STATION OR1	OR2
SYSTEM 1	0.99216	0.99216	0.99216
TOTAL :	0.99216		

INVESTMENT		MEASURE OF EFFECTIVENESS	
TOT INVESTM. =	1561625.0	AVAILIABILITY =	0.99216
PERC E S S =	20.8	N C R S =	0.18822
PERC FIRST LEVEL=	57.3	WAITING TIME =	0.00169
PERC LRU =	91.3	RISK OF SHORTAGE =	0.001599
PERC SRU =	8.7	RSK SHRTGE(1ST LVL)=	0.001599

F.5. EXAMPLES OF SIMPLE OUTPUT

The output obtained from SIMPLE is illustrated in Table F-12. In this table, each line includes the value of each variable, the variable name, and its definition.

Table F-12.

```
*************************************************************

     SIMPLE,OUTPUT DATA (BASIC VERSION)

*************************************************************

   1)  4666829.CC    LSC      : LIFE SUPPORT COSTS,DISCOUNTED,NY YEARS
   2)   804315.000   A        : INITIAL INVESTMENT,SUPPORT ACTIVITIES
   3)  3862514.CC    RN       : ANNUAL RECURR. COSTS,NY YEARS
   4)   223551.812   R        : ANNUAL RECURR. COSTS
   5)  2034667.CC    TMANPW   : LSC,MANPOWER
   6)   356156.437   TTSE     : LSC,T&SE
   7)  1694450.CO    TINVEN   : LSC,INVENTORY
   8)   193719.375   TTRAIN   : LSC,TRAINING
   9)    29420 7.437 TTRANS   : LSC,TRANSPORTATION
  10)    93630.750   TOTHER   : LSC,OTHER ELEMENTS
  11)        0.C     AM       : INITIAL MANPOWER COSTS,EXCL. TRAINING
  12)   155190.000   AS       : T&SE,INIT. INVESTMENT
  13)   543445.CCC   AI       : INVENTORY,INITIAL PROVISIONING
  14)    63CC0.CC0   AC       : TRAINING,INITIAL
  15)        0.0     AT       : TRANSPORTATION,INITIAL COSTS
  16)    42680.000   AO       : OTHER INVESTMENT COSTS
  17)  2034667.C0    RM       : MANPOWER COSTS,RECURRING,NY YEARS
  18)   200966.437   RS       : T&SE,SUPPORT OF,NY YEARS
  19)  1151CC5.CC    RI       : INVENTORY,RECURRING COSTS,NY YEARS
  20)   130719.375   RC       : TRAINING,RECURRING COSTS,NY YEARS
  21)   29420 7.437  RT       : TRANSPORTATION COSTS,NY YEARS
  22)    50950.754   RO       : OTHER RECURRING COSTS,NY YEARS
  23)  2505913.C0    DLTL1    : DELTA COST,LRU1 DISC. AT FAILURE
  24) 15231875.C     DLTL2    : DELTA COST,LRU2 DISC. AT FAILURE
```

25)	2654869.00	DLTL3	: DELTA COST,LRU3 DISC. AT FAILURE
26)	3891048.00	DLTL4	: DELTA COST,LRU4 DISC. AT FAILURE
27)	17350544.0	DLTL5	: DELTA COST,LRU5 DISC. AT FAILURE
28)	14155255.0	DLTL6	: DELTA COST,LRU6 DISC. AT FAILURE
29)	1238664.00	DLTS1	: DELTA COST,SRU1 DISC. AT FAILURE
30)	44560.043	DLTS2	: DELTA COST,SRU2 DISC. AT FAILURE
31)	30782.785	DLTS3	: DELTA COST,SRU3 DISC. AT FAILURE
32)	4311864.00	DLTS4	: DELTA COST,SRU4 DISC. AT FAILURE
33)	166224.437	DLTS5	: DELTA COST,SRU5 DISC. AT FAILURE
34)	2781537.00	DLTS6	: DELTA COST,SRU6 DISC. AT FAILURE
35)	63966.227	DLTS7	: DELTA COST,SRU7 DISC. AT FAILURE
36)	633935.437	DLTS8	: DELTA COST,SRU8 DISC. AT FAILURE
37)	87755.562	DLTS9	: DELTA COST,SRU9 DISC. AT FAILURE
38)	27041.645	DLTS10	: DELTA COST,SRU10 DISC. AT FAILURE
39)	508446.375	DLTS11	: DELTA COST,SRU11 DISC. AT FAILURE
40)	45600.000	ASO	: T&SE,INVESTM. ORG-LEVEL
41)	1200.000	ASOA	: T&SE,INVESTM. ORG-LEVEL,COMMON
42)	44400.000	ASOO	: T&SE,INVESTM. ORG-LEVEL,PECULIAR
43)	74160.000	ASI	: T&SE,INVESTM. INT-LEVEL
44)	500.000	ASIA	: T&SE,INVESTM. INT-LEVEL,COMMON
45)	73660.000	ASIO	: T&SE,INVESTM. INT-LEVEL,PECULIAR
46)	35430.000	ASD	: T&SE,INVESTM. DEP-LEVEL
47)	450.000	ASDA	: T&SE,INVESTM. DEP-LEVEL,COMMON
48)	34980.000	ASDO	: T&SE,INVESTM. DEP-LEVEL,PECULIAR
49)	409490.000	AICL	: INVENTORY,INVESTM. LRU'S
50)	118475.000	AICS	: INVENTORY,INVESTM. SRU'SEVEL
51)	15480.000	AICU	: INVENTORY,ENTERING COSTS
52)	48000.000	ACO	: TRAINING,INITIAL,ORG-LEVEL

```
53)      6000.000  ACI      : TRAINING,INITIAL,INT-LEVEL
54)      9000.000  ACD      : TRAINING,INITIAL,DEP-LEVEL
55)      0.0       ACCF     : TRAINING,EQUIPMENT
56)      1200.000  ACOD     : DOCUMENTATION,ORG-LEVEL
57)      1800.000  ACID     : DOCUMENTATION,INT-LEVEL
58)      1680.000  ACDD     : DOCUMENTATION,DEP-LEVEL
59)     24000.000  ACOG     : SPACE COSTS,ORG-LEVEL
60)     14000.000  ACIG     : SPACE COSTS,INT-LEVEL
61)      0.0       ACDG     : SPACE COSTS,DEP-LEVEL
62)      0.0       ACCM     : CONTRACTING COSTS,MEETINGS ETC
63)      0.0       ACCE     : OTHER INITIAL COSTS
64)    189614.937  RMOCN    : MANPOW. COSTS,CORR.MAINT.ORG-LEVEL,NY Y
65)     15883.508  RMOC     : MANPOW. COSTS,CORR.MAINT.ORG-LEVEL,ANN.
66)    258685.437  RMICN    : MANPOW. COSTS,CORR.MAINT,INT-LEVEL,NY Y
67)     21669.352  RMIC     : MANPOW. COSTS,CORR.MAINT.INT-LEVEL,ANN.
68)    333179.312  RMDCN    : MANPOW. COSTS,CORR.MAINT.DEP-LEVEL,NY Y
69)     27909.492  RMDC     : MANPOW. COSTS,CORR.MAINT.DEP-LEVEL,ANN.
70)   1045755.69   RMOPN    : MANPOW. COSTS,PREV.MAINT.ORG-LEV. NY Y
71)     87600.000  RMOP     : MANPOW. COSTS,PREV.MAINT.ORG-LEV. ANN.
72)    171905.000  RMIPN    : MANPOW. COSTS,PREV.MAINT.INT-LEV. NY Y
73)     14400.000  RMIP     : MANPOW. COSTS,PREV.MAINT.INT-LEV. ANN.
74)     35527.043  RMDPN    : MANPOW. COSTS,PREV.MAINT.DEP-LEV. NY Y
75)      2976.000  RMDP     : MANPOW. COSTS,PREV.MAINT.DEP-LEV. ANN.
76)     58304.461  RSOON    : T&SE,SUPP. COSTS,ORG-LEVEL,NY YEARS
77)      4884.000  RSOO     : T&SE,SUPP. COSTS,ORG-LEVEL,ANNUAL
78)     96727.562  RSION    : T&SE,SUPP. COSTS,INT-LEVEL,NY YEARS
79)      8102.598  RSIO     : T&SE,SUPP. COSTS,INT-LEVEL,ANNUAL
```

80)	45934.465	RSDON	: T&SE,SUPP. COSTS,DEP-LEVEL,NY YEARS
81)	3847.800	RSDO	: T&SE,SUPP. COSTS,DEP-LEVEL,ANNUAL
82)	326404.250	RICLN	: REPLENISHMENT,LRU'S,NY YEARS
83)	27341.965	RICL	: REPLENISHMENT,LRU'S,ANNUAL
84)	213481.000	RICSN	: REPLENISHMENT,SRU'S,NY YEARS
85)	17882.703	RICS	: REPLENISHMENT,SRU'S,ANNUAL
86)	380122.937	RICKN	: REPLENISHMENT,CONSUMERABLES,NY YEARS
87)	31841.824	RICK	: REPLENISHMENT,CONSUMERABLES,ANNUAL
88)	129342.687	RIIKN	: REPLEN.CONSUMAB. INT-LEVEL,NY YEARS
89)	10834.676	RIIK	: REPLEN.CONSUMAB. INT-LEVEL,ANNUAL
90)	250780.187	RIDKN	: REPLEN.CONSUMAB. DEP-LEVEL,NY YEARS
91)	21007.148	RIDK	: REPLEN.CONSUMAB. DEP-LEVEL,ANNUAL
92)	230997.375	RICVN	: OTHER INV.RECC. COSTS,NY YEARS
93)	19350.000	RICV	: OTHER INV.RECC. COSTS,ANNUAL
94)	114603.312	RCON	: RECURR. TRAINING,ORG-LEVEL,NY YEARS
95)	9599.996	RCO	: RECURR. TRAINING,ORG-LEVEL,ANNUAL
96)	10744.062	RCIN	: RECURR. TRAINING,INT-LEVEL,NY YEARS
97)	900.000	RCI	: RECURR. TRAINING,INT-LEVEL,ANNUAL
98)	5372.031	RCDN	: RECURR. TRAINING,DEP-LEVEL,NY YEARS
99)	450.000	RCD	: RECURR. TRAINING,DEP-LEVEL,ANNUAL
100)	77605.625	RTON	: TRANS. ORG-LEVEL,NY YEARS
101)	6500.805	RTO	: TRANS. ORG-LEVEL,ANNUAL
102)	214954.437	RTIN	: TRANS. INT-LEVEL,NY YEARS
103)	18006.129	RTI	: TRANS. INT-LEVEL,ANNUAL
104)	1647.423	RTCEN	: TRANS. COMMON COSTS,NY YEARS
105)	138.000	RTCE	: TRANS. COMMON COSTS,ANNUAL
106)	5586.914	RCCDN	: DOCUMENTATION,RECURR. COSTS,NY YEARS
107)	468.000	RCCD	: DOCUMENTATION,RECURR. COSTS,ANNUAL

108)	45363.840	RCCGN	: SPACE,MAINT. CF,NY YEARS
109)	3800.001	RCCG	: SPACE,MAINT. OF,ANNUAL
110)	0.0	RCCEN	: OTHER RECURRING COSTS,NY YEARS
111)	0.0	RCCE	: OTHER RECURRING COSTS,ANNUAL
112)	722.312	TNLRUF	: AVERAGE REPAIRS/YEAR,LRU'S
113)	600.204	TNSRUF	: AVERAGE REPAIRS/YEAR,SRU'S
114)	68.186	AFL1	: ANNUAL # CF FAILURES,LRU1
115)	264.176	AFL2	: ANNUAL # CF FAILURES,LRU2
116)	52.560	AFL3	: ANNUAL # CF FAILURES,LRU3
117)	105.876	AFL4	: ANNUAL # CF FAILURES,LRU4
118)	131.400	AFL5	: ANNUAL # CF FAILURES,LRU5
119)	100.114	AFL6	: ANNUAL # OF FAILURES,LRU6
120)	113.173	AFS1	: ANNUAL # CF FAILURES,SRU1
121)	30.275	AFS2	: ANNUAL # CF FAILURES,SRU2
122)	11.734	AFS3	: ANNUAL # CF FAILURES,SRU3
123)	212.007	AFS4	: ANNUAL # CF FAILURES,SRU4
124)	18.523	AFS5	: ANNUAL # CF FAILURES,SRU5
125)	114.416	AFS6	: ANNUAL # CF FAILURES,SRU6
126)	8.410	AFS7	: ANNUAL # OF FAILURES,SRU7
127)	36.965	AFS8	: ANNUAL # CF FAILURES,SRU8
128)	14.302	AFS9	: ANNUAL # OF FAILURES,SRU9
129)	5.066	AFS10	: ANNUAL # CF FAILURES,SRU10
130)	35.334	AFS11	: ANNUAL # CF FAILURES,SRU11
131)	291.200	XMS	: MTBF,SYSTEM
132)	11.94	DF	: DISCOUNT FACTOR,NY YEARS
133)	10.63	RDF	: REDUCED DF,(NY-2) YEARS

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